2006 MRS Fall Meeting Provided Expansive Overview of Cutting-Edge Technical Themes

Hynes Convention Center and Sheraton Boston Hotel • Boston, Mass.
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The 2006 Materials Research Society Fall Meeting was held in Boston, Mass., at the Hynes Convention Center and Sheraton Boston Hotel, November 27–December 1, 2006. It was chaired by **Babu Chalamala** of Indocel Technologies, **Louis J. Terminello** of Lawrence Livermore National Laboratory, and **Helena Van Swygenhoven** of Paul Scherrer Institute.

The meeting featured 42 technical symposia in the areas of Soft Matter—Active Materials, Hybrids, and Sensors; Electronics, Photonics, and Magnetics; Energy Storage and Utilization; Microstructure, Mechanics, and Modeling; Characterization Tools and Techniques; and topics of general interest including nuclear waste management and actinides. Complementing the technical talks were the exhibition featuring more than 225 international exhibitors from all sectors of the global materials science and engineering communities, the plenary session, awards ceremony, funding seminars, and other special activities including the inaugural Scientific Film Festival for professionals and amateurs, as well as the second Hydrogen Fuel Cell Car Race for high school students and teachers.

Soft Matter—Active Materials, Hybrids, and Sensors

Biosurfaces and biointerfaces represent an emerging area of basic and applied research that lies at the confluence of bioscience, nanoscience, and microelectronics. The development of engineered biointerfaces that enable a controlled bioresponse of materials platforms toward biotechnology applications was featured in Symposium D, with particular emphasis on materials and surface chemistries that are engineered with nanometer precision. Dip-pen nanolithography, in which molecules, nanoparticles, and even viruses can be transferred as “inks” from an AFM tip to a substrate with great precision, was discussed by C. Mirkin (Northwestern Univ.) He and his team of researchers have produced a nanoarray consisting of 55,000 dip-pen tips per cm^2. Dip-pen technology is compatible with both hard matter and soft matter and is a high-resolution, direct-write method that is viable for a range of substrates. Whereas other scanning probe lithographies deliver energy to the substrate, dip-pen nanolithography delivers material to the surface, Mirkin said. This makes it an excellent choice for the production of ultrahigh-density gene chips and proteomic arrays as well as for chemical and biological sensors. The technology can be used under ambient conditions. “We can begin to pattern on the scale of biology itself,” Mirkin said. “Viruses, cells, maybe even proteins.”

A major challenge is to get all tips in contact with the substrate at once. To meet this challenge, Mirkin and his colleagues have developed what they call the “soft

Giant Carbon Nanotube Construction

On Tuesday November 28, at the 2006 MRS Fall meeting, Wendy Crone and Dana Horoszewski from the University of Wisconsin-Madison MRSEC created large-scale balloon models of carbon nanotubes with balloon artists Todd Neufeld and Patty Sorell. This interactive activity was developed by UW-MRSEC for the Nanoscale Informal Science Education (NISE) Network as a way to get the public excited about nanoscience. The largest nanotube model created was 10-ft tall, 7 ft in diameter with a bond length of 30 inches; meeting attendees were encouraged to add on balloons to the smaller nanotube models, which eventually grew to over 6 feet long.

The NISE Network is a collaboration between science museums, research institutions and societies and individuals who are committed to educating the public about nanoscale science and engineering. MRS is a NISE Network partner and is actively recruiting scientists and engineers to get involved in public education about nanoscience. The NISE Network has a guidebook for scientists who want to get more involved with public science education titled “Nano and the Public: A Collaboration Opportunity for Researchers and Museums” which is available from the NISE Network.

landing" approach. First, they coat the cantilevers of the dip-pen tips with gold, and then they rest the array on a sacrificial substrate; the weight of the array aligns the tips and brings them into contact with the substrate simultaneously when the sacrificial substrate is removed. To date, Mirkin's group has used this technology to examine cell surface binding events involving the 18-nm-diameter tobacco mosaic virus, and has developed the ability to control the orientation of the virus on the substrate. The researchers have also produced influenza virus nanoarrays.

Hydroxyapatite (HA), with a chemical formula of $Ca_{10}(PO_4)_6(OH)_2$, is an analog for the mineral component of bones. It is bioactive, forming stable bonds with bone *in vivo*, but it has low tensile strength and fracture toughness as compared to bone. In an effort to overcome these drawbacks, A. White (Univ. of Cambridge) has been investigating the possibility of strengthening HA by forming a composite with carbon nanotubes (CNTs). As White described in Symposium D, the CNTs were functionalized by reaction with nitric and sulfuric acids, which placed hydroxyl and carboxyl groups on the surface of the nanotubes. After mixing 5 wt% CNTs in HA, drying, grinding, pressing the mixture into tablets, and sintering them, White analyzed the composites using TEM and SEM. Functionalized CNTs showed greater interactions with HA than did nonfunctionalized ones. The functionalized CNT composites were less dense and more porous, which might aid in the bonding with bone *in vivo*, said White. Preliminary tests showed that human osteoblasts survived on the CNTs, demonstrating that nanotubes are not toxic in this application. Cultured cells grew slightly better on the HA–CNT composite than on pure HA after 14 days, demonstrating that reinforcing HA with CNTs may prove to be a viable method to enhance the strength and fracture toughness of HA.

In Symposium A on responsive soft matter, O.D. Velev (NCSU) talked about miniature devices that couple to external fields so as to power motion such as self-propelling micromachines that can be controlled by internal logic. Another example of the microworld getting smarter included smart microvalves that can constantly flow an ultra-micro amount of water with high accuracy, as discussed by A. Suzuki (Yokohama Natl. Univ.). C. Liu (UIUC) discussed the potential for integrating piezo-resistive polymer nanocomposites into all-polymeric MEMs structures for tactile sensors.

According to R.T. Hanlon (Marine Biological Lab., Woods Hole, Massachusetts), the ultimate soft skin belongs to octopuses. The ability of the octopus to morph within milliseconds into a colorful coral ambient is a great inspiration for their study, as described in Symposium A. Indeed, if it is found in nature, it can as well be done in the laboratory, said Hanlon.

In a presentation on artificial muscles and sensors, in Symposium C, R. Baughman (Univ. of Texas–Dallas) described CNT yarns with giant Poisson ratios of up to 4.2, meaning that they amplify an applied tensile strain to achieve a volume contraction 20 times greater than ordinary materials. Stretch these materials in certain directions and they become denser, Baughman said. He also discussed mate-

ACRONYM KEY

2D: two-dimensional
3D: three-dimensional
ACS: American Chemical Society
AFM: atomic force microscopy
AFOSR: U.S. Air Force Office of Scientific Research
AFRL: U.S. Air Force Research Laboratory
ANL: Argonne National Laboratory
ARL: U.S. Army Research Laboratory
ARO: U.S. Army Research Office
ASU: Arizona State University
BAW: bulk acoustic wave
CAS: Chinese Academy of Sciences
CMOS: complementary metal oxide semiconductor
CMU: Carnegie Mellon University
CNM: Centro Nacional de Microelectrónica
CNT: carbon nanotube
CONICET: Consejo Nacional de Investigaciones Científicas y Técnicas
CVD: chemical vapor deposition
DARPA: Defense Advanced Research Projects Agency
DMR: Division of Materials Research
DOE: U.S. Department of Energy
EBSD: electron backscatter diffraction
EDS: energy-dispersive spectroscopy
EPFL: École Polytechnique Fédérale de Lausanne
ESPR: ellipsometric surface plasmon resonance
FEM: finite element method
FET: field-effect transistor
FIB: focused ion beam
GE: General Electric
Georgia Tech: Georgia Institute of Technology
HA: hydroxyapatite
HKUST: Hong Kong University of Science and Technology
HRTEM: high-resolution transmission electron microscopy
HTS: high-temperature screening
IC: integrated circuit
IIT: Indian Institute of Technology
IR: infrared
ISN: Institute for Soldier Nanotechnology
JHU: Johns Hopkins University
JPL: Jet Propulsion Laboratory
LANL: Los Alamos National Laboratory
LBNL: Lawrence Berkeley National Laboratory
LC: liquid crystal
LCN: liquid crystal network
LED: light-emitting diode
LLNL: Lawrence Livermore National Laboratory
MBE: molecular beam epitaxy
MEMS: microelectromechanical systems
MIT: Massachusetts Institute of Technology
MLCT: metal-to-ligand charge transfer
MOCVD: metalorganic chemical vapor deposition
MPI: Max-Planck-Institute
NCSU: North Carolina State University
NEMS: nanoelectromechanical systems
NIM: negative index of refraction meta-material
NIMS: National Institute for Materials Science
NMR: nuclear magnetic resonance
NRC: National Research Council
NREL: National Renewable Energy Laboratory
NRL: Naval Research Laboratory
NSF: National Science Foundation
ODS: oxide dispersion strengthening
OLED: organic light-emitting device
ONR: Office of Naval Research
ORNL: Oak Ridge National Laboratory
OSU: Ohio State University
PEM: proton-exchange membrane
PLD: pulsed laser deposition
PNNL: Pacific Northwest National Laboratory
R&D: research and development
rf: radio frequency
RHEED: reflection high-energy electron diffraction
RPI: Rensselaer Polytechnic Institute
SAW: surface acoustic wave
SEM: scanning electron microscopy
SNL: Sandia National Laboratories
SPM: scanning probe microscopy
SPR: surface plasmon resonance
STM: scanning transmission microscopy
TEM: transmission electron microscopy
UC: University of California
UCSB: University of California–Santa Barbara
UCSD: University of California–San Diego
UHTC: ultrahigh temperature ceramics
UIUC: University of Illinois at Urbana–Champaign
UniMoRe: University of the Studies of Modena and Reggio Emilia
UV: ultraviolet
WPAFB: Wright-Patterson Air Force Base

rials with negative Poisson ratios that expand laterally when stretched uniaxially. By blending mixtures of single-walled CNTs with multiwalled CNTs, Baughman and his colleagues produced CNT sheets whose Poisson ratio could be tuned from positive to negative at will.

Electronics, Photonics, and Magnetics

The problem of power generation at the nanoscale, a burning topic in nanotechnology, was addressed by Z.L. Wang (Georgia Tech) through his research on the structural and electrical characteristics of ZnO nanowires. The compressive and tensile strains induced through the bending of a nanowire by an AFM tip is transduced into a negative and a positive electric field, respectively, through the piezoelectric effect, which can then be sensed by the same AFM tip. The resultant voltage can then be used for energy generation. During his presentation in Symposium Q, Wang coined the term "nano-piezotronics" to describe this work. His findings may see future applications in biomedical devices, wireless sensors, and portable electronics.

N.A. Sanford (NIST, Boulder, Colorado) discussed the growth of nanowires of various materials. In his talk in Symposium I, Sanford said that III-nitride nanowires are of particular interest because GaN/AlGaN UV lasers must be made using materials with low defect densities and there is a lack of a suitable lattice-matched substrate on which to grow them. The nanowires start off with defects as they are growing but become defect-free. The low surface recombination velocity of GaN overcomes the large surface-to-volume ratio of the wires and allows potential devices to function. The wires grown by MBE show faceted hexagons at the ends of the wires, which strongly suggests that no catalytic action of droplets is involved. Indium nitride wires show similar results.

Also in Symposium I, M. Shur (RPI) talked about the current intense interest in terahertz (THz) technology, including imaging, radio astronomy, environmental control, explosive detection, communications, medicine, dentistry, and homeland security. There is a gap at ~1 THz in the power-frequency plot for devices between the electronic devices at the low end and photonic devices at the higher frequencies. This THz gap can be filled by nitride-based devices, according to Shur's investigations. Nitrides have excellent properties including high mobility, saturation velocity, sheet carrier concentration, and breakdown field. In utilizing plasma-wave propagation in nitride devices, Shur draws similarities to shallow water wave propagation. This mode allows the fabrication of resonant detectors, emitters, photomixers, and the more conventional mixers. The wave actually travels faster than the electrons, resulting in THz frequencies, Shur said.

In Symposium J, electronics involving diamond was discussed. R.J. Nemanich (previously at NSCU; now at ASU) described how diamond could be used as a device to directly convert heat into electricity. Using a hydrogen treatment of the diamond surface, a low work function can be achieved, which decreases with temperature. A thermionic conversion device has been fabricated that operates up to 600°C with an open circuit voltage of 0.4 V which is sufficiently high to allow combination of the devices without expensive interconnection techniques.

In Symposium L, J. Linnros (Royal Institute of Technology, Stockholm) showed some measurements obtained on single silicon quantum dots. The dots he investigated were formed by oxidizing pillars of silicon and using the fact that in regions of high stress, oxidation is inhibited. The oxidation creates a small volume at the highly stressed end of the pillar that remains as single-crystal silicon while the rest of the pillar turns to oxide. At low temperatures (35 K and 80 K), he was able to get photoluminescent spectra that showed a main line with some replica spectra (due to spherical and torsional modes of phonon interaction). The linewidth of the main lines was less than kT which demonstrates the discrete nature of the excited states, reinforced by the fact that the emission energy varies from dot to dot. Some of the quantum dots blinked and Linnros linked this to discrete on and off states with single electrons leaving and then returning to the dot. He emphasized that a large number of dots must be analyzed for proper conclusions to be drawn.

In his talk in Symposium V, R. Mahajan (Intel) reported how lead-free techniques for packaging have had a significant effect on both technical and business issues. Lead-free technology combined with copper interconnects and low-κ dielectric makes silicon circuit fabrication and package and board integration more complex. Integration requires a reduction in the inner layer stress to avoid die, passivation, substrate, underfill, dielectric cracking, and interconnect solder fatigue. Risk areas for lead-free technology include brittle fracture, solder fatigue, creep, vibration, and pad cratering. Reliability drives a need for alternative alloys. Reducing the amount of silver in the alloy can improve the interface toughness by increasing the bulk compliance and the plastic energy dissipation.

Energy Storage and Utilization

Symposium Z on Hydrogen Storage Technologies began with an overview talk by S. Satyapal (DOE) covering the goals and progress of the U.S. National Hydrogen Storage Project related to hydrogen-powered vehicles. Some key targets are

MRS Medalist Mark Thompson Describes Evolution of Organometallic Complexes in OLEDs

Mark Thompson of the University of Southern California focused his MRS Medalist talk on the use of organometallic complexes in developing OLEDs. Thompson's group has prepared a range of intensely luminescent Ir(III), Pt(III), and other complexes, with applications in both monochromatic and white OLEDs. The goal is the design of new materials for high-efficiency OLEDs. These devices all emit from phosphorescence complexes; however, the device architecture and the materials requirements vary significantly for monochromatic devices of different colors (e.g., blue versus red emission) and white OLEDs. Thompson described the design and measurements of transport, blocking, and emitting materials specifically for these different devices. He summarized the results by demonstrating that heavy metal complexes can form highly efficient OLEDs. In particular, he stressed that "metals are good; expensive ones are better." Strong spin-orbit-coupling leads to efficient phosphorescence. The results show that both carrier and exciton trapping at the phosphor are critical for high efficiency. The phosphorescent OLEDs were observed to cover the entire color gamut including UV and near-IR. "Tuning" of the phosphorescence was also possible by carefully controlling the ligand and MLCT states, he said.

system gravimetric capacity, volumetric capacity, and cost with targets of 6 wt%, 2.5 kW/L, and $4/kWh for 2010 and 9 wt%, 2.7 kWh/L, and $2/kWh for 2015. Satyapal noted that these are "systems" requirements, rather than materials requirements, so the materials themselves need to do considerably better. Other targets include efficiency and kinetics. Currently DOE is looking at all technologies, saying it is too early to eliminate options. "No current system meets targets, but there are some materials with potential," Satyapal said. Most likely high pressure tanks will be needed in the near-term, but other solutions (e.g., metal hydrides, carbon, and chemical hydrogen) will be needed for the long term. As some examples, metal hydrides have challenges related to heat management, desorption temperature, and kinetic response. Chemical hydrogen storage has an issue of regeneration. Carbon hybrids with adsorbents have problems with volumetric capacity and the need for cold temperatures for refueling. Overall, there is a particular need for theoretical modeling of materials systems, targeting prediction of novel materials and reactions, thermodynamics, kinetics, and mesoscale modeling, Satyapal said.

While U.S. Department of Energy targets for hydrogen storage are systems-level targets, much of the research and development work focuses on the properties and characteristics of the materials that are part of the system. A new tool at Argonne National Laboratory has been developed to help evaluate materials to see how they relate to potential storage systems. In Symposium Z, G. Thomas presented on behalf of R. Ahluwalia (ANL) how this tool, MHtool, functions based on various inputs. The Excel spreadsheet has modules covering characterization, storage capacity, heat transfer, systems, and dynamics. It is not yet publicly posted, but it will be available free by registering, Thomas said.

One of the research highlights of Symposium Z was the application of high-throughput methodologies to hydrogen storage materials discovery. R. Griessen of Vrije Universiteit, the Netherlands, showed a high-throughput screening (HTS) methodology based on optical transparency measurements to obtain hydrogen storage properties such as heat of dehydrogenation and kinetics. Other organizations such as GE and NIST have also presented HTS methodologies.

During the past 15 years, battery energy density has tripled, power has increased by a factor of 10, and cost has been reduced by a factor of 10, said K.M. Abraham (E-KEM Sciences, Massachusetts) in his presentation on "Prospecting for a Counterpart of Moore's Law for Rechargeable Batteries" in Symposium BB. Whereas these advances are impressive, they do not compare to the doubling (or more) of the number of components on an IC that occurs every two years in the semiconductor industry, Abraham said in reference to the familiar Moore's law. Abraham outlined the history and some of the challenges of meeting the growing demand for powering portable electronics, cordless power tools, and vehicles. The complexity of materials for batteries due to conversion reactions, ion transport, and other factors makes it difficult to match Moore's law. Abraham said that new discoveries are needed rather than just incremental changes. As one example, he described using nanophase materials to reduce the diffusion length for reactants and enable high reversibility. He also described a lithium/air system based on displacement chemical reactions as potential routes to 500–2000 Wh/kg rechargeable batteries.

To improve the properties of lithium battery electrodes, M. Miyayama and his colleagues at the University of Tokyo have been producing nanosheets of tetratitanate, which was discussed in Symposium AA. Nanosheets were chosen to limit the diffusion distance that Li^+ ions must traverse in the power-generation process. The researchers prepared tetratitanate nanosheets 300-nm wide, a few microns long, and 2-nm thick. Measurements made after these nanosheets had been deposited on a glass substrate showed a capacity per unit area of 10 mV/s. Assuming that all Ti^{3+} ions oxidize to Ti^{4+}, this would mean that the capacity of these nanosheets is about twice that of standard lithium electrodes. The researchers also prepared composites of tetratitanate nanosheets with carbon fibers which had a very high specific capacity. The researchers concluded that the redox reaction in 2-nm-thick tetratitanate nanosheets gives a capacity larger than that predicted by theory: greater than one Li^+ ion for one Ti^{4+} ion.

In Symposium QQ, P.G. Bruce (Univ. of St. Andrews, UK) discussed the role of mesoporous transition oxides in energy storage. Mesoporous materials have pores that are 2–50 nm in diameter, walls between pores that are 2–10-nm thick, and surface areas ranging 70–500 m^2/g. Making such materials from transition metal oxides is notoriously difficult, said Bruce, but worth the effort. Confining the *d* electrons of the transition metals in thin walls produces new magnetic, electrical, and optical properties that are valuable in such applications as catalysis, gas adsorption, magnetism, and energy storage. Referring to a study of the rechargeable lithium battery, Bruce said that the transfer of Li^+ ions in one direction and electrons in the other is the mechanism responsible for electricity generation in this type of battery. Substituting mesoporous electrodes in place of the current bulk electrodes could significantly improve performance and lifetime, Bruce said. The high surface area of a mesoporous material enables the facile transport of Li^+ ions across the interface; the thin walls make for a short diffusion distance for Li^+ and electrons; and solid-state reactions can occur that are impossible in the bulk. For example, using a mesoporous ß-MnO_2 as the positive electrode switches on the electrochemistry, Bruce said, allowing the insertion of 0.9 Li per Mn. Similarly, using a mesoporous Co_3O_4 spinel as the negative electrode enables charge storage above the theoretical limit due to the formation of a reversible polymeric surface layer; this extra storage capability disappears when mesoporosity is lost.

Microstructure, Mechanics, and Modeling

Spider silk is a unique biomaterial with tremendous potential for both nano- and macro-materials, according to R. Lewis (Univ. of Wyoming) during a discussion in Symposium DD. Spiders produce six different types of silk, along with a glue that gives it its stickiness. One type, called major ampullate silk, has strength and "energy-to-break" properties that are at least as high as Kevlar, whereas other types are more elastic and flexible. Silk goes from a liquid to a solid in 0.1 s at room temperature; this transformation takes place simply by pulling on the liquid, suggesting that it is mainly a physical, as opposed to a chemical, process.

Lewis and his colleagues have been trying to understand the properties of natural silk in order to synthesize artificial silk materials. All "drag line" silks have two proteins, MaSp1 and MaSp2, with recurring amino acid motifs. Polyalanine and polyglyal make β-sheets, while the GPGXX sequence (G, glycine; P, proline; X, any amino acid) forms β-spirals that act like elastic springs. Lewis found that synthetic silk fibers with increased levels of polyalanine showed higher tensile strength than those with lower levels.

For further details on the research results reported at the 2006 MRS Fall Meeting, see the following symposium summaries. Proceedings as well as additional meeting highlights are available online at www.mrs.org.

Sophisticated Results Achieved

with Soft Matter
(See MRS Proceedings Volume 947E)

About 150 talks were presented in Symposium A on Responsive Soft Matter—Chemistry and Physics for Assemblages, Films, and Forms. Mere numbers characterize the symposium as little as the number of pictures would characterize the Guggenheim Museum. The masterpieces of scientific achievements presented in the symposium encompassed sophisticated new forms of soft matter created atom by atom, molecule by molecule, layer by layer, to obtain functionality that further bridges the gap between humans and machines.

One of the forms of soft matter, polymer brushes, open the prospect of designing an inexpensive, simple, and robust biosensor platform that could be tuned to separate or respond to many different biological species. Incorporation of numerous chemical functionalities was shown to modify the ability of the thermally-responsive polymer gradient to mineralize inorganics, adsorb nanoparticles, or bind biomolecules (S. Diamanti, WPAFB; NRC). S. Yang (Univ. of Pennsylvania) said that surface wettability can be dynamically tuned from highly hydrophobic to superhydrophilic properties with the grafting of thin layers of thermoresponsive polymer brushes. Such "smart" surfaces may enable spatially controlled self-assembly of nanoparticles in response to a small temperature change.

A number of presentations revealed substantial advantages of LC polymer network actuators compared to inorganic materials: LC polymers are easy to process, the chemical composition provides wide control of their properties, and LC polymers are capable of deformations orders of magnitude larger than inorganic actuators. The variety of stimuli for LC networks discussed at the meeting included temperature, chemical agents such as humidity or pH, electrical fields, and light. These properties can be combined with photo-patterning processing techniques (C. van Oosten et al., Eindhoven University of Technology). The typical elastic modulus of the newly developed LCN actuators with splayed molecular alignment is 1 GPa, ensuring internal work density of 42 kJ/m^3. The process is reasonably fast, with a time constant of 0.25 s, and yields in rather strong deformation with a minimum radius of 0.66 mm.

Azo LC polymers may exhibit even faster and larger deformations in conditions when the effect of a light consists in reorientation of the LC rather than reduced order parameter. Using focused laser beams, such a polymer could be deformed in a spatially localized manner (N.V. Tabiryan, Beam Engineering for Advanced Measurement, Corp., Florida) and brought into high-frequency (~50 Hz) nonlinear dynamic oscillations due to the feedback between the polymer film geometry and the laser beam.

As an alternative to covalently bonded monomers, LC polymers were introduced where some covalent bonds were replaced by hydrogen bridges (D.J. Broer, Philips Research; Eindhoven Univ. of Technology). Such polymers exhibit mechanical response by a controlled and reversible rupture of the hydrogen bridges. A new class of LC networks is formed when the hydrogen-bridged benzoic acid monomers are polymerized in their smectic state.

Applications of soft materials extend to morphing aerostructures. The adaptive structures of future air vehicles will likely integrate several active materials technologies into hierarchical structured composites that operate synergistically (J.W. Baur, WPAFB). For example, there are opportunities for reinforcing shape-memory polymers with high modulus fibers to obtain the high specific modulus values typical of most aerospace structural materials without compromising the ability of the polymer to deform.

At the opposite end of the scale of applications of responsive soft matter is the NanoCar (K. Kelly, Rice Univ.), which is a molecule with four fullerene wheels connected by rotating alkyne axles to a central chassis. It is not quite ready for a ride yet and needs to be towed at the STM tip. The effects of surface–molecule interactions on the direction and speed of motion were thus characterized and the ability to control directional motion in molecular-sized nanostructures was demonstrated. The plausible applications include surface

Knut Wolf Urban Delivers Von Hippel Award Address on New Paradigm of TEM

Nearly 20 years after his first talk at an MRS Meeting, Knut Wolf Urban of Forschungszentrum Jülich presented his Von Hippel Award address. In an MRS symposium in 2001, he said, a packed room listened to his report on the first results obtained by aberration-corrected transmission electron microscopy (TEM), a technique he introduced shortly before, along with Max Haider and Harald Rose. The topic of Urban's present lecture was a report on how this technique had changed TEM in the five years that have past since this memorable event. While aberration correction can reduce the point spread of an electron image to a value close to zero, contrast is also needed. The origin of the contrast in atomic resolution TEM are phase shifts introduced to the electron wave field by the atomic potential. These need to be converted to amplitude contrast. Urban showed that this can be brought about by operating the aberration corrector of the new instrument not in the fully corrected mode but with a small negative value of the spherical aberration adjusted. This novel and unexpected operation mode enables the achievement of maximum resolution at a level of contrast not known to have been achieved before. Urban showed several examples demonstrating the power of an aberration-corrected TEM. In 2003, this technique was used to study O atoms in $SrTiO_3$. Other examples include imaging N in Si_3N_4 and in GaN, and B in MgB_2. Urban used the example of O in $SrTiO_3$ to demonstrate how quantitative information on local stoichiometry can be obtained.

The story continues. Urban showed how even more information can be extracted using this technique. All of the information is present in the exit plane wave function of the electron beam. By capturing different images by varying the lens focus, one can reconstruct the complex electron wave function. Urban showed the example of quantitative comparison of a dislocation core structure in $SrTiO_3$, wherein simulated images and experimental data could be quantitatively compared. A 5-pm accuracy can currently be achieved. Urban concluded by briefly describing the U.S. DOE project called TEAM which, by the end of the decade, through a combination of spherical and chromatic aberration correction, will achieve the goal of 0.5 Å resolution.

catalysis and nanoscale tribology with not a word about nanotransportation yet.

The combination of soft matter with a solid opens new opportunities. A new generation of highly sensitive and low-noise IR detectors is in the horizon owing to ultrasensitive thermal bimorph actuators (T.J. Bunning, WPAFB). The microcantilever bimorph fabricated by depositing a polymer thin film on a stiff polysilicon cantilever undergoes huge, reversible bending in response to heating. Temperature resolution approaching 0.2 mK with thermal sensitivities reaching 2 nm/mK have been demonstrated, both of which are superior to standard ceramic–metal structures.

Symposium Support: AFRL, DARPA, and ONR.

Properties, Characterization, and Devices of Polymer-Based Dielectrics Explored

(See MRS Proceedings Volume 949E)

Symposium C on Smart Dielectric Polymer Properties, Characterization, and Their Devices focused on transducers, dielectric insulators, and charge storages made of polymers. The Symposium covered topics related to materials development, characterization, processing, manufacturing, analysis, device designing, and applications.

In the area of polymer-based piezoelectrics, R. Gerhard (Univ. of Potsdam, Germany) proposed to explore and utilize the so-called Maxwell–Wagner polarization, an often unwanted bipolar charging of the interfaces in heterogeneous dielectrics. Such Maxwell–Wagner piezoelectrets could provide higher acoustic impedances than cellular polymer ferroelectrets. Dielectric polymers and nanocomposites are a class of electroresponse polymers offering great potential for storing and controlling the electric energy and power in power electronics as well as microelectronics. Polymer nanocomposites with high dielectric constant across a broad temperature and frequency range and low loss are required for many of these applications. Employing the percolation approach and using organic shell which is compatible with the polymer matrix to achieve uniform distribution of Ag nanoparticles in the composite, C.-W. Nan (Tsinghua Univ., China) reported a nanocomposite with a dielectric constant above 1000 and loss less than 4% in a flat frequency response up to 10 MHz and temperature up to 120°C. J. Calame (NRL) presented the microstructure-based simulation of the dielectric properties of polymer–ceramic composites which took into account detailed microstructures on the dielectric properties and breakdown strength. Calame showed that the interface properties can make a significant contribution to the dielectric properties. In addition, the local field fluctuation in the composite may lead to reduction of the breakdown strength. To address the needs of dielectric polymers with high electric energy density, low loss, and fast discharge time in power electronics for hybrid electric vehicles, electric weapon systems, and medical devices, a report was delivered from Q. Zhang's group at Pennsylvania State University on the development of a class of polar-fluoro polymers that possess very high electric displacement and breakdown field and low remnant polarization, which are the necessary conditions for high-energy-density dielectric materials. It was shown that by properly tuning the dielectric constant of the polymer to avoid the "early" polarization saturation, a very high electric energy density (~25 J/cm^3) can be achieved with the discharge time in less than 1 ms. T. Marks (Northwestern) presented results of thin dielectric polymer films with a high dielectric constant suitable for the gate dielectric of organic thin-film transistors which significantly reduces the operation field range (from 100 V to 1 V range as required in microelectronics). For organic semiconductors, *n*-type materials with high performance are highly desirable. Marks also reported recent work in developing *n*-type organic semiconductors that can be easily vapor-deposited with $I_{on}/I_{off} > 10^4$ and mobility $\mu_e \sim 0.85$ cm^2/V-s. The ferroelectric polymer for memory application has been an interesting topic in recent years, and T. Furukawa (Tokyo Univ. of Science) demonstrated that the heating generated by the polarization switching is the key response to the fatigue observed in the memory devices made from ferroelectric polymers.

Symposium Support: 3M Co. and Trek, Inc.

Surfaces Biologically Tailored to Achieve Device Enhancements

(See MRS Proceedings Volume 950E)

Symposium D on Biosurfaces and Biointerfaces focused on the development of engineered biointerfaces that enable a controlled bioresponse of material platforms toward biotechnology applications. D.R. McKenzie and his colleagues at the University of Sydney, Australia are attempting to increase the functional activity of proteins bound to surfaces by applying electric fields to increase the density of bound proteins and to optimize their orientation. The researchers' goal is to produce improved biosensor surfaces, which typically use an attached protein, antibody, or enzyme to bond with a target analyte in solution. Another possible application is surfaces for biofuel cells. Ideally, researchers would like to be able to bind a protein, antibody, or enzyme in high density at a chosen location on a surface and with the desired orientation. They want to be able to quantify the degree of such surface attachments, and would like the attached molecules to remain functional for a long time. Strong covalent bonds to the surface are preferred.

McKenzie used a surface plasmon resonance (SPR) cell for adsorption studies of horseradish peroxidase in an electric field. By applying an electric field below the level at which electrophoresis would occur, he was able to increase the concentration of horseradish peroxidase near the substrate to a small extent. Further experiments using ellipsometric SPR (ESPR), which provides data on both the amplitude and phase of light reflected from the substrate surface, proved to be more suc-

Panelists of "Women in MS&E Breakfast" Advise that Researchers in Industry Identify Their Strengths and Weaknesses

If you are one of those women who wants to see your ideas in practice in only a few years, industry may be the way to go. A panel of scientists working in the industrial sector spoke at the Women in MS&E Breakfast. Among the pros of industry, said **Lucille Giannuzzi** of FEI Company, is the resource support to do your work quickly. **Lynne Gignac** of IBM T.J. Watson Research Center agreed. Some of the cons, Gignac said, are the lack of job security and diminishing benefits such as pension and health insurance. Although the number of women materials researchers working in industry is low, the panelists agree that the number can increase. It is up to the researchers to determine whether industry is where they want to be and to be aware of their own strengths and weaknesses so as to locate the position where they will be happiest. The best advice from **Pradnya Nagarkar** of 3M Company is to "identify your core competency and change the playing field to suit your core competency." In other words, women researchers need not follow a path already paved to advance their careers but to determine the path as they identify what they have to offer to help their company progress.

cessful. The researchers were able to monitor the kinetics of adsorption of soybean peroxidase by cycling the applied voltage between –2 V and +2 V. Successive cycles produced quantitative increases in soybean peroxidase attachment along with selective orientation of the molecule on the surface. This could suggest a pathway to better biosensors with higher concentrations of detector molecules on the electrode surface, McKenzie said.

Bioelectronics involves the melding of biology with micro- and nano-electronics. Such devices might be used for biological sensing, the development of biological algorithms for information processing systems, and possibly for therapeutic devices. A. Offenhausser (Forschungszentrum Jülich, Germany) demonstrated the effectiveness of coupling DNA with a field-effect transistor (FET) to detect single nucleotide polymorphisms in DNA. A single nucleotide polymorphism is a variation in a single nucleotide of a DNA chain that may be responsible for some disease states. But detection of a deviant single nucleotide is not easy. A probe DNA strand with a known nucleotide sequence was covalently bonded to the electrode surface, followed by a target DNA strand to be analyzed. By using an FET in impedimetric mode, Offenhausser's group was able to differentiate between a target strand that was a perfect match for the probe strand, a target strand with one nucleotide mismatch, and a target strand with two nucleotide mismatches, thereby demonstrating that the impedimetric FET system can act as a sensitive detector of polymorphisms in DNA strands.

V. Sokolova and her colleagues at the University of Duisburg–Essen, Germany, used calcium phosphate (CaP) nanoparticles to transport DNA into the cytoplasm of transformed human umbilical vein endothelial cells (T-HUVEC). They prepared nanoparticles of CaP functionalized with DNA (CaP/DNA) and a combination of DNA and bovine serum albumin (CaP/DNA/BSA). As a control, they also prepared DNA/BSA with no CaP. Red fluorescing markers added to the nanoparticles enabled their positions to be followed using laser confocal microscopy. The researchers found that after 1 h, the CaP/DNA particles had adsorbed onto the cell membrane; after 2 h, they had penetrated into the cytoplasm. The CaP/DNA/BSA particles took 2 h to adsorb onto the cell membrane and 8 h to penetrate into the cytoplasm. Later, they were found to be accumulated near the membrane of the nucleus of the cell. The control DNA/BSA did not succeed in penetrating the cell, demonstrating that the CaP nanoparticle is critical to the process. These results could have some significance for gene transfer applications, according to the research team.

Symposium Support: Genzyme Corp. and Q-Sense, Inc.

Austen Angell's David Turnbull Lecture Addresses Phenomenology of Glassformers

Austen Angell (right) receives David Turnbull Lectureship honor from 2006 MRS President Peter Green.

In his David Turnbull Lecture, Austen Angell of Arizona State University addressed the two major classes of questions confronting anyone interested in the phenomenology of glassformers. The first is the question of why some substances, the glassformers, can be supercooled into glasses rather than crystallizing to the thermodynamically more stable state. The second is the question of how liquids behave when their cooling is not cut short by crystallization. Angell said that David Turnbull, one of his heroes of science, has made major contributions in both these areas.

On the question of how liquids behave when crystals do not form, Turnbull pioneered the study of glass transitions in metallic alloys, measuring the heat capacity change at the glass transition (Tg) for the first time, and, with colleagues, developing the free volume model for the temperature-dependence of liquid transport properties approaching Tg. Angell's group has extended the phenomenological picture to include networks where free volume does not play a role, and to reveal a pattern of behavior that provides for a classification of glassformers (from "strong" to "fragile"). Turning to supercooled water, Angell discussed the puzzling divergences observed that are now seen as part of a cooperative transition that leads to very untypical glass transition behavior at lower temperatures—when crystallization is bypassed by hyperquenching. Angell said that their interpretation of water behavior can be seen as a bridge between the behavior of the "strong" (network) liquids of classical glass science (e.g., SiO_2), and the "fragile" behavior of typical molecular glassformers.

In summary, he said, glasses form in systems where the molecules, ions, or atoms, cannot form good three-dimensional packing. Systems can be "tuned" to conditions where possible crystals have equal low-lattice energies when crystallization is frustrated, and glasses can consequently form. When crystals do not form, the low-temperature liquid can be studied and very interesting behavior is revealed.

Angell concluded by stating that the theoretical description of the low-temperature liquid behavior remains a big challenge and is an excellent problem to be tackled by anyone interested in condensed matter and materials science.

Nanofunctional Materials to Play a Role in Biological and Chemical Detection

(See MRS Proceedings Volume 951E)

Biological and chemical detection is a growing need in light of current security-related events. Despite continued advancements in various aspects of sensor technology, numerous challenges remain to be addressed including reliability, selectivity, sample collection, sample preparation, and false alarm rates. Symposium E addressed the various challenges faced in chemical and biological detection and the important role that advances in nanofunctional materials, nanostructures, and devices are playing to solve these intricate problems. In a tutorial, T. Thundat (ORNL) gave an in-depth review of the challenges facing the research and development of practical, economically viable, and useful biological and chemical sensors. Thundat introduced the advantages that nanotechnology brings to this field, with its successful implementation hinging on the improvement of the fundamental understanding of the relationship between the structure, morphology, and composition of nanomaterials and their exhibited functional behavior.

Multiple speakers addressed this gap in various sessions. Plasmonics is a particular area where recent research has shown a big potential for application in high-sensitivity chemical and biological detection, but numerous fundamental questions are yet to be answered. A.A. Lazarides (Duke Univ.) presented experimental and theoretical data showing that a metal nanoparticle assembly supports plasmon resonances and exhibits optical band modulations that are sensitive to the assembly composition, structure, and interparticle spacing. The implication is that plasmonic coupling in metallic nanoparticle assemblies can be controlled and engineered for biological sensing applications. Most plasmonic substrates are designed to operate in the visible and infrared parts of the spectrum. F. Tam (Rice Univ.) studied and demonstrated the possibility of extending the use of plasmonic substrates in the mid-IR part of the spectrum using mesoscopic nanoshell platforms. Tam showed that by using two different core–shell geometries, it is possible to tune plasmon resonances at two different wavelengths in the mid-IR.

Symposium Support: GE Global Research Ctr. and Motorola Labs., ESPS.

Integrated Nanosensors Enable Detection of Multiple Stimuli
(See MRS Proceedings Volume 952E)

The driving forces behind the development of integrated nanosensors, the topic of Symposium F, are the diverse range of applications (e.g., detection of IR radia-

Symposium X Covers Biomaterials, Advanced Materials, OLED Display Technology, and History of Materials

Symposium X on Frontiers of Materials Research offers lunchtime overviews of particular topics in materials research to the nonspecialist. Subra Suresh (MIT) and Kristi S. Anseth (Univ. of Colorado) addressed materials contributions to the field of medicine. Gregg A. Zank discussed innovations in advanced materials at Dow Corning, Corp., Ching W. Tang (Univ. of Rochester) covered the development of OLED display technology, and Dierk Raabe (MPI–Dusseldorf) entertained the lunchtime crowd with a look at materials throughout history.

Materials Research Crosses Paths with Medical Arena

Suresh gave an overview of the intersection of cell mechanics, nanotechnology, and medicine in his *Acta Materialia* Gold Medal Award Lecture. In the past 5–10 years, scientists and engineers have developed the tools necessary to look at the mechanical properties of individual biological cells and molecules. Specifically, "laser tweezers" that act like the grips of a standard tensile strength-testing machine can measure the stiffness and deformability of biological materials at the cellular level to a force resolution of a picoNewton. "Changes in mechanical properties at the cellular level can have a significant effect on disease states," Suresh said.

As proof of this statement, Suresh described the research that he and his team at MIT have done in cooperation with scientists at the National University of Singapore and the Institute Pasteur in Paris. Suresh used two examples to illustrate his presentation: malaria and cancer. Using laser tweezers, the researchers were able to determine the stiffness and deformability of normal red blood cells and those infected with malaria-inducing parasites. Normal red blood cells have a diameter of about 8 μm. In their movement through the circulatory system, they must squeeze through capillaries with diameters of 2.5 μm, and then elastically spring back to their normal size in wider blood vessels. A typical red blood cell might traverse the circulatory system about a million times during its 120-day lifetime in the body. Suresh showed a movie of a healthy blood cell being stretched to twice its length numerous times using laser tweezers. Similar tests with a malaria-infected blood cell showed the cell's inability to deform at all, which causes it to clog pathways in the circulatory system and vital organs. Recent research performed in collaboration with scientists at the Institute Pasteur showed that a particular protein called "ring-infected erythrocyte surface antigen" (RESA) was responsible for the stiffening of the cell. Tensile tests performed after RESA was "knocked out" of a red blood cell, using gene disruption techniques, showed that it regained its elasticity. So mechanical tests showed that RESA plays an important role in increasing the stiffness of red blood cells in certain stages of malaria parasite maturation inside them.

The researchers saw the opposite effect while studying epithelial pancreatic cancer cells. Cancer cells, whose internal molecular structure is altered by exposure to certain bioactive lipids naturally produced in the human body, proved to be extremely pliable, giving them the ability to squeeze through small pores in tissues. This increased mobility might promote the spread of cancer from one site to another. Thus, stress and strain tests have become an important tool in the understanding of human diseases at the cellular level. "We can now use biomechanics to quantify how cells stretch, stick to, and move through blood vessels, impair organs, and affect disease states," Suresh said.

In another Symposium X presentation on materials and the medical field, Anseth demonstrated how hydrogels, which she described as "water-swollen polymeric network systems," might be used to deliver living cells to a target area in the body to help the healing process or mitigate the effects of a disease. These gels are 95–99% water, with a crosslinked network of macromolecules providing the structure. The presentation covered both permissive and promoting gels and looked at their applications to collagen restoration, Parkinson's disease, and mesenchymal stem cell viability.

A permissive gel is one that simply allows cells to function in a controlled 3D environment in the body; it does not induce the cells to action. Promoting gels are active, prompting the cells to secrete more of a particular protein, for instance. Permissive gels are being examined for cartilage regeneration. Cartilage, which is composed of water, chondrocytes, collagen, and proteoglycans, has a limited ability to heal itself. The mesh size of hydrogels made of poly(ethylene glycol) and water can be tuned by modifying the crosslinking density of the polymer. By adjusting the mesh to the proper size to allow collagen cells to move and interact, researchers have been able to produce cartilage *in vivo* with properties similar to that of natural cartilage. "Cartilage is closest on the horizon," Anseth said, to a practical application of hydrogels for tissue regeneration.

Parkinson's disease is a much greater challenge. By the time it is diagnosed, patients have lost most of their dopaminergic neurons that control motion. Previous attempts at inserting new dopaminergic neurons into a patient's brain have shown that only 10% of the cells survive one week, while only 1% of the neurons survive one year. "New neurons must integrate with existing neurons to get functional synapses," Anseth said. Toward that end, she and her colleagues are studying proliferation of dopaminergic cells in degradable PEG hydrogels. Tuning the hydrogels to degrade at the right rate might

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tion, explosives, gas phase toxins, and pathogens in food products), the development of sensitive biosensors (e.g., DNA, proteins, bacteria, and neurons), and the integration of these into a single platform to allow for the simultaneous detection of multiple stimuli.

In an introductory talk, J.T. Devreese (Univ. of Antwerp, Belgium) addressed the important significance of Richard Feynman's 1959 Christmas lecture on the birth of nanotechnology, which was corroborated by lectures showing the substantial performance improvements in nanosensing devices. Advances in vapor phase explosive detection were described by A. Rose (Nomadics, Cambridge, Mass.) who detailed the targeted materials and transduction mechanisms. W.C Trogler (UCSD) explored the mechanism of chemo-resistive sensors for the rapid detection of gas phase toxins such as warfare agents (e.g., Sarin and Soman) and pesticides. C. Bath (Cornell) addressed the timely detection of pathogenic microorganisms in food products. A class of polymer-based systems with various ranges of applications, including the development of actuators, MEMS/NEMS, and drug-delivery systems was discussed by N. Chopra (Univ. of Kentucky). A real-time cancer detection system by integrating a cell array with a microlens array was

Continued from page 267

be a key to success. Studies have shown that stimulation of the cells with gamma-aminobutyric acid induces neuronal activity in the hydrogel.

Researchers Embark on Journey through Materials and Time

"Dow Corning knows how to do three key reactions, and knows how to do them very, very well," said Zank, Vice President and Chief Technology Officer for Dow Corning Corp. This "core chemistry set" predictably involves the conversion of SiO_2 and methyl groups to form silicone polymers, the product that Dow Corning uses in many different applications. Zank described many of these products and applications as a way of outlining the trends in industry and society that Dow sees and responds to.

In the paper industry, silicone acts as the release layer for reversible paper adhesives, like those used in name tags. A new version of this technology allows Dow Corning's partner/customer Herma GmbH in Stuttgart, Germany, to coat and cure silicone on pressure-sensitive labels at a production rate of about 60 miles of labels per hour. For the insulation industry, the company's silica precursors are used by Aspen Aerogels to produce insulating materials composed of 95–97% air. These aerogels are mesoporous fractal materials that slow down the passage of heated air by creating a tortuous gas flow path, which leads to lower thermal conductivity. Holographic recording of data in photopolymers is being used for storage of archival data in Dow Corning Enterprises–Aprilis; here, the refraction index gradient stores the digital ones and zeros. A novel silicone dilatant compound that is flexible in its relaxed state, becomes rigid under a high stress impact, and returns to its flexible state once the stress is removed is being used in a new, comfortable body armor system called the Active Protection System. It is intended to protect children active in sports, the elderly, motorcycle enthusiasts, and others by providing comfortable, easy-to-wear garments that will prevent injuries. Zank provided other examples of Dow Corning's ubiquitous presence in the materials market, including lip gloss, solar energy panels, and industrial microlithography processes with ultrathin resist layers. He concluded with a message that bodes well for materials scientists in the coming years, "Advances in materials are fueling all this innovation that we see."

Tang took the audience on a virtual trip through time to show the development of OLED technology from 1965 to the present. Starting with the seminal paper of 1965 that described the discovery of organic luminescence in anthracene, Tang moved to his own 1987 paper detailing vapor-deposited molecular thin films and engineered ohmic contacts. Tang emphasized the importance of the Alq molecule, which introduced high-injection current, low-drive voltage, high-brightness efficiency, and fast response into the OLED equation. He also noted Friend's 1990 article in *Nature* titled "Light-Emitting Diodes Based on Conjugated Polymers," which has been cited almost 5,000 times in the literature, and Baldo et al.'s 1999 article that announced the discovery of electrophosphorescence from Ir(ppy)3. In 2001, the Watanabe group at Pioneer extended the lifetime and increased the stability of OLEDs. Kido introduced stacking of transparent OLEDs in 2003 to achieve 100 cd/A. Tang also spoke of the addition of microcavities to these devices, which could increase the efficiency to 200 cd/A. He ended his presentation by comparing the properties of a series of OLED displays made by various companies using different approaches to the technology.

In what surely qualifies as the most humorous talk given at this meeting, Raabe took a look at materials throughout history. The presentation included numerous references to various mythologies, an introduction to the first beer can invented in 1820, and a discussion of the composition of the blood of Star Trek's Mr. Spock.

"Please don't take this seriously," Raabe began, as he launched into an exploration of the role that gold has played in civilization. This segment included a discussion of the stupidity of King Midas, whose wish to have everything he touched turn to gold almost led to his starvation.

Raabe delved into the story of Prometheus, the Greek god who gave fire to humans and was punished by having his liver eaten every night by an eagle only to have it grow back the next day. Raabe deemed this to be the first example of regenerative medicine. Similarly, the substitution of ivory into the shoulder of Tantalos's son was the world's first implant. The trip through materials history touched on copper, the substance in Mr. Spock's blood that transported oxygen; titanium, including a cartoon of Arnold Schwarzenegger's character in the movie *Terminator IV*; and steel, whose brittleness at low temperature caused the sinking of the Titanic, "not some floating ice cube," according to Raabe. The British bayonet was designed not to stab but to open cans of food, he said.

In between this humorous onslaught, Raabe spoke more directly about Damascene steel, which is a forged composite of hard and soft irons that is still produced in its highest quality in Japan today; the honeycomb microstructure that accounts for the stiffness of the carapace of a lobster; and the slow technology transfer rate that brought iron ore reduction to Europe about 1500 years after the process was discovered in Anatolia, Turkey, and Syria. Raabe even waxed philosophically once, noting that "using metals produced a strong change in man's world view and his view of the gods." This tremendous change contributed to the self-confidence of humans, making further technological progress possible. Sometimes even Raabe takes things seriously.

presented by A. Kummel (UCSD), whereas the integration of nanophotonics biosensors in lab-on-a-chip microsystems was discussed by A. Llobera (CNM, Bellaterra, Spain). B.H. Kasemo (Chalmers Univ. of Technology, Gothenburg, Sweden) used multiple techniques relevant for (stem) cell engineering, drug targeting, and biosensing. For the detection of neurotransmitters, a hybrid organic–inorganic structure holds considerable promise as a chemical sensor platform, as shown by G.R. Borghs (IMEC, Leuven, Belgium). S.D. Bader (ANL) discussed the possibilities offered by nanobiomagnetic sensing, and porous Si (M.J. Sailor, UCSD) and alumina (F. Casanova, UCSD) were discussed for their ease of fabrication and potential uses in biosensing.

The growing interest in the development of new functional materials for integrated nanosensors was addressed by G.J. Brown (WPAFB), who focused on type-II superlattices for IR arrays; M.J. Schoening (Aachen Univ., Germany), on the coupling of semiconductor FET together with chemical and biological recognition elements; and P.M. Fauchet (Univ. of Rochester), on silicon photonic bandgap structures.

Biofilm–Material Interactions and Materials-Based Infection Control
(See MRS Proceedings Volume 954E)

Bacterial infections of implanted biomedical devices and tissue surfaces constitute an ever-increasing threat to human health with significant clinical and economic consequences. In many infections, bacteria attach to the surfaces of medical devices or compromised tissue and subsequently develop into highly cooperative communities known as biofilms. Bacteria in a biofilm are well protected from host defenses and antibiotics, almost all of which have been developed to combat bacteria in their planktonic state. Lacking alternative strategies, infected biomedical devices ranging from catheters to orthopedic implants are simply removed. Particularly for in-dwelling devices, such a procedure can substantially compromise the success of a subsequent revision surgery, produce extensive patient discomfort, and lead to rapidly escalating health-care costs. The key goal of Symposium H on Biofilm–Material Interactions—New Tools, Technologies, and Opportunities was to provide a forum to assess, from widely varying perspectives, how nanotechnology, microreactor systems, surface chemistry, and modern concepts of microbiology can be integrated and exploited to revolutionize the way researchers both study and respond to biofilm-associated infectious diseases in the coming decade. This symposium attracted a multidisciplinary group of scientists and engineers. Their presentations demonstrated that much is known within the many relevant subdisciplines associated with biofilm–material interactions. There were, for example, presentations that addressed the development of new surfaces that can hinder the adhesion of bacteria. However, the symposium underscored the growing need for cross-disciplinary interactions between materials engineers, microbiologists, cell biologists, and clinicians to better define the various disparate attributes required by various biomedical devices such that their intended clinical function is preserved while the effects of bacterial adhesion, proliferation, and catastrophic infection are simultaneously mitigated. This symposium made clear that infection control is a growing component of biomaterials design.

Advances Made in III–V Nitride Semiconductor Materials and Devices
(See MRS Proceedings Volume 955E)

The opening session of Symposium I focused on the use of III-N materials for spintronics. By controlling the quantum spin state of electrons, increased speed, power efficiency, and storage density are possible in spintronics devices. K. Sato (Osaka Univ.) presented results of Monte Carlo calculations for AlGaInN alloys doped with transition metal atoms. These calculations indicate that high transition metal concentrations are necessary in order to have ferromagnetic ordering at room temperature. However, cluster formation during epitaxial growth may lead to islands of transition metal atoms that result in room-temperature ferromagnetic observations. The session also included reports of ferromagnetic behavior in III-N alloys doped with rare-earth atoms. Since the rare-earth atoms can be optically active in these materials, magnetic and optical functionality on a single chip may be possible.

The AlGaInN materials system is also ideally suited for the fabrication of deep UV devices operating at wavelengths below 280 nm. Optoelectronic devices based on these alloys are key components

Hydrogen Fuel Cell Model Car Challenge

The hydrogen fuel cell model car challenge held at the 2006 MRS Fall Meeting is an activity designed to involve local high school students in a materials science-related activity. It offers students from local area high schools a hands-on, active learning experience about hydrogen, fuel cells, and car building from experts in these fields. Student teams designed and assembled their own hydrogen fuel-cell–powered model cars on-site, then placed their cars on the race tracks.

The winning teams of the hydrogen fuel cell model car challenge were:
First Place: Norwell High School, Norwell, MA
Second Place: Plymouth North High School, Plymouth, MA
Third Place: E.O. Smith High School, Storrs, CT

The event was sponsored by General Motors, the Department of Energy, the National Renewable Energy Laboratory, and Energy Conversion Devices.

of numerous commercial and military systems for sensing, communications, and sterilization. To realize the desired UV applications, fabrication of high-quality epilayers with Al-alloy compositions in excess of 40% is required. Furthermore, the common use of sapphire substrates leads to significant defect generation and related doping issues that have a huge impact on device efficiencies. M.A. Khan's group (Univ. of South Carolina) has developed various innovative approaches to overcome these material growth issues and to achieve deep UV emitters and photodetectors. The key to their efforts is a migration-enhanced MOCVD procedure for the growth of epilayers with high Al compositions. In addition, their new pulsed lateral overgrowth techniques have yielded extremely low-defect AlGaN layers with Al compositions well over 50%. These high-quality AlGaN layers were then processed into LEDs with milliwatt-power emission at wavelengths as low as 270 nm. Initial data for AlGaN *p-i-n* photodetectors demonstrate high voltage reverse-bias operation and peak responsivity at 280 nm.

Symposium Support: ARO.

Uses of Diamond for Electronics Explored

(See MRS Proceedings Volume 956)

Symposium J, dedicated to the use of diamond as an electronic material, covered the range of topics from the growth and doping of single-crystal and nanocrystalline diamond to the realization of a range of types of electronic devices. Progress on the use of single-crystal material for the fabrication of high-frequency and high-power diamond diodes and transistors were reported by B. Yost (Harris International Inc.), where the use of CVD-grown material displaying electron mobilities of about 4500cm^2/Vs had led to unprecedented power levels. The launch of the new company Diamond Microwave Devices (DMD Ltd), a joint venture between Element Six (E6) and Filtronic, was announced, whose aim is to commercially exploit this work. J. Yang (NRL; NOVA Research Inc., Virginia) gave insight into the process of "lift-off" of single-crystal diamond grown by CVD from its single-crystal substrate, which can then be re-used. A rare insight into the practical issues was offered, with time-lapse photography revealing just how slow the process can be.

Away from conventional electronics, one session addressed the potentially revolutionary topic of quantum information processing. J.-F. Roch (École Normale Superieure de Cachan, France) highlighted how color centers in diamond can be used as sources of single photons, whereas manipulating single spins was addressed by R. Hanson (UCSB) and J. Wrachtrup (Univ. of Stuttgart, Germany). The use of nitrogen-vacancy defect centers as qubits was discussed; these could be created in ordered arrays by ion-implantation. The use of diamond devices for biosensing was also a strong theme within the symposium, with H. Kawarada (Waseda Univ., Japan) showing that DNA hybridization could be detected using diamond solution gate field-effect transistors.

Symposium Support: Apollo Diamond Inc.; CEA-LIST; Harris International, Inc.; Seki Technotron USA; and sp3 Diamond Technologies, Inc.

Bright Future in Store for ZnO in Solid-State Lighting, Large-Area Displays, and Beyond

(See MRS Proceedings Volume 957)

ZnO and related compounds, the topic of Symposium K, have drawn considerable interest in recent years due to the larger exciton binding energy, availability of single-crystal substrates, and radiation hardness of these materials that make them ideal candidates for solid-state lighting and space applications.

M. Kawasaki (Tohuku Univ.) covered a broad spectrum of topics including observation of the Quantum–Hall effect in ZnO, and the fabrication of LEDs by using temperature-modulation MBE growth. S.J. Pearton (Univ. of Florida) discussed Ohmic and Schottky contacts, doping by ion implantation, and the use of ZnO nanowires for LEDs and sensors. Y. Lu (Rutgers) demonstrated the suitability of ZnO for multifunctional applications such SAW devices and sensors. A theoretical discussion on the role of defects in controlling the electronic properties of ZnO was presented by S. Zhang (NREL). Nanostructures of ZnO, and their piezoelectric and luminescent properties, were presented by J.W.P. Hsu (SNL). E. Fortunato (New Univ. of Lisbon, Portugal) gave an overview of the commercial potential of transparent electronics and the suitability of ZnO and related materials for thin-film transistors and displays.

L.J. Brillson (OSU) discussed the role of surfaces and interfaces in controlling Schottky diode properties on ZnO and the

Fundamental Materials Research Key to Meeting Future Energy Needs

The plenary lecture was given by Pat Dehmer, director of the Office of Basic Energy Sciences (BES) within the Office of Science at the U.S. Department of Energy. Dehmer said that abundant energy is intimately linked with global stability, economic prosperity, and quality of life. However, even with aggressive conservation and energy efficiency measures, the projected increase in population accompanied by rapid technology development and economic growth is projected to double the demand for energy by mid-century and more than triple the demand by the end of the century. Dehmer said that these energy challenges cannot be met by incremental improvements to existing technologies, but that transformational changes and disruptive technologies will be required to provide clean, reliable, economic solutions. As in the past, many of these changes will likely come from fundamental research in the physical sciences, according to Dehmer. In a series of workshops, her department has been exploring basic research needed for a hydrogen economy, solar energy conversion, solid-state lighting, a superconducting grid, and for advanced nuclear energy systems. Additional workshops are planned in areas of geological waste disposal, electrical energy storage, and the broad impacts of catalysis and advanced materials on energy technologies. By effectively linking discovery and use-inspired sciences with energy technology goals, the reports from these workshops have generated a great deal of interest in the science and technology research communities in the United States and around the world. Significant new funding has resulted in Dehmer's department.

2006 Materials Research Society Fall Meeting.

influence of ozone plasma treatment on interfaces. Optical properties of ZnO quantum wells and the influence of the spin-exchange interaction were presented by B. Gil (Univ. of Montpellier). A. Hoffmann (Technische Universität–Berlin) discussed photoluminescence and Raman studies on a variety of ZnO crystals and epilayers. Bulk and epitaxial growth issues were covered, respectively, by T. Fukuda (Tohoku Univ., Japan) and H. Kato (Stanley Electric Co., Japan). *P*-type doping issues were discussed by Z. Ye (Zhejiang Univ., China) and S.-J. Park (Gwangju Inst. of Science and Technology, South Korea).

Symposium Support: AFOSR and ARO.

Increasing Emphasis Placed on Device Applications of Group-IV Semiconductor Nanostructures

(See MRS Proceedings Volume 958)

Symposium L was focused on group IV semiconductor nanostructures including novel Si- and SiGe-based systems (e.g., Stranski–Krastanov self-assembled nanostructures, ultrathin silicon-on-insulators, NEMS, and advanced electronic and photonic nanostructures). The overall content of the Symposium, when compared with previous symposia in this series, had increased emphasis on device applications as opposed to basic materials science, indicating considerable maturity in this field. Interesting developments presented during the Symposium include new Si-based nanostructures and a nanoscale ballistic transistor.

O.G. Schmidt (MPI–Stuttgart) reported on a method to make rolled-up Si-based nanotubes and discussed their potential applications. The tubes are formed when partially relaxed Si films are released from Ge substrates by selective under-etching of the substrates. The Si layers roll downward by the initial tensile strain on the substrates. On the other hand, partially relaxed InGaAs films on AlAs substrates roll upward by the initial compressive strain on the substrates. This indicates a possibility to control the nanotube chirality. Schmidt's group has formed radial SiO_2/Si superlattices by the rolling of partially relaxed oxidized Si films. This structure could be used to produce Si nanoscale optical waveguides and resonators. Schmidt also reported the integration of InAs quantum dots into rolled-up InGaAs/GaAs nanotubes, which shows a potential to realize high-Q flexible optical resonators based on the rolled-up nanotubes. This technique could be applied to the SiGe system.

M.G. Lagally (Univ. of Wisconsin–Madison) reported on a way to make Si-based nanomembranes and their applications. The nanomembranes are formed when ultrathin SiGe multilayer structures are released from silicon-on-insulator (SOI) substrates by selective under-etching of the SiO_2 layers with HF solution. The released nanomembranes can then be easily transferred to new substrates such as Si wafers with different orientations or to flexible substrates. The elastic strain changes after the release from the substrates alter the electronic properties of ultrathin SiGe multilayer structures. Lagally's group has made thin-film transistors with a high-carrier mobility of several hundreds of $cm^2V^{-1}s^{-1}$ by using Si/SiGe/Si nanomembranes.

M. Lundstrom (Purdue Univ.) analyzed a nanoscale ballistic transistor. According to his calculations, the modern microelectronic industry has practically reached the limit of the transistor's speed. It is possible that we might witness the end of the famous "Moore's Law," Lundstrom said. At the same, there is no reason to see any saturation in the integrated circuit's performance, most likely due to increasing circuit complexity, introduction of multiprocessors, and such. That was one of the interesting conclusions of the open-floor-discussion session which concluded the five-day Symposium. Other intriguing open-ended subjects such as the feasibility of a Si-based laser compatible with CMOS technology (thought to be unlikely) were also discussed in that session.

Symposium Support: ARO and LLNL.

Growth, Behavior, and Applications of Quantum Dots Presented

(See MRS Proceedings Volume 959E)

Epitaxially-grown and colloidal-synthesized quantum dots have largely been classified and studied as two separate materials systems. Both have distinct advantages such as the biocompatibility of colloidal quantum dots and relative ease of microelectronic integration of epitaxial quantum dots. Now, A. Madhukar (Univ. of Southern California) presented work from his group on hybrid epitaxial and colloidal quantum dot structures for highly sensitive quantum biodetection applications. Theoretical and experimental results were presented on interdot energy transfer between surface patterned colloidal quantum dots and buried epitaxial quantum dots. The new possibilities and large opportunity that exists for further study in this area was highlighted in Symposium M on Quantum Dots—Growth, Behavior, and Applications.

Other important topics discussed included work on high-efficiency blue nanocrystal LEDS, patterning of epitaxial quantum dots by focused ion beams, droplet epitaxy of unique quantum structures (e.g., rings), and theoretical modeling of quantum dot growth.

Symposium Support: RHK Technology, Inc. and Veeco.

Self-Assembly Aided by Energetic Ion- or Photon-Beam Irradiation

(See MRS Proceedings Volume 960E)

The nanostructure of surfaces plays a critical role in many optical, magnetic, and electronic applications, such as surface-enhanced Raman scattering, magnetic information storage, and quantum dot electronics. The focus of Symposium N was on the self-assembly of surface and near-surface nanostructures through the use of energetic ion beams, including low- and high-energy ions and photons. The discussions on pattern formation by ion beams covered various novel and outstanding challenges including nanoscale control of crystalline orientation by a combination of channeling and sputtering (J.M.E. Harper, Univ. of New Hampshire); nanostructuring through ion etching and epitaxy (F.B. de Mongeot, Univ. of Genova, Italy); regimes of linear stability under ion irradiation (M.J. Aziz, Harvard); kinetic mechanisms of ion rippling (E. Chason, Brown Univ.); material shaping by high-energy ions (A. Vredenberg, Utrecht, Netherlands); and large-area pattern formation on various surfaces, including metals, insulators and semiconductors, and in sub-surface layers by metal ion implantation. The discussion on surface patterning by photon irradiation suggests that this area of research is likely to grow tremendously as various novel effects can be observed, including dewetting-instability–induced pattern formation in nanoscopic metal films (R. Sureshkumar, Washington Univ.–St. Louis); preferential desorption through resonant absorption of photons (B. Wu, CAS, Beijing; and P.I. Cohen, Univ. of Minnesota); and electronic-excitation assisted self-assembly (H.-J. Ernst, CEA Saclay, France). Two novel experiments were also discussed: one combined ion and photon irradiation to achieve reversible control of nanostructure (N. Kishimoto, NIMS, Tsukuba, Japan); the other discussed fluctuation x-ray microscopy to characterize medium-range order (L. Fan, ANL). The Symposium also addressed a variety of applications of energetic beams, including growth of vertically aligned CNTs; control of surface wetting properties by ion sputtering; large-area metal nanoarrays through electron-beam–assisted damage to diblock copolymers; and fabrication of nanostructures on silicon carbide using ion-amorphization and thermal oxidation.

Symposium Support: ORNL and Washington Univ., Ctr. for Materials Innovation.

Applications Emphasized in Nanostructured and Patterned Materials in Information Storage

(See MRS Proceedings Volume 961E)

Symposium O covered the latest advances in the area of magnetic storage and cross-point memories, in particular, nanofabrication methods required to produce some of the smallest structures needed for storing information. Presentations from Hitachi Research (by Z. Bandic for T. Albrecht) and Seagate Research (by D. Weller) provided the latest advances in the effort to produce high-density bit-by-bit patterned media as well as heat-assisted magnetic recording, indicating that the magnetic storage industry will remain vital for many years to come. Latest results in nanoimprint lithography and challenges in making templates were presented by G. Schmid and D. Resnick (Molecular Imprints, Inc., Texas). C.T. Rettner (IBM Research), in what was perceived as the most engaging talk of the symposium, showed prototype memory devices, some with lithographically controlled sub-10-nm dimensions. T. Nishida and E. Dobisz from Hitachi Research showed that electron-beam lithography is the superior way to control all things smaller than 50 nm. That the optical lithography is still highly relevant was shown in the talk by H. Solak from Paul Scherrer Institute in Switzerland—dot arrays with densities more than 500 Gb/in.^{2} were fabricated by extreme UV interference lithography. In the self-assembly session, results were presented by S.-K. Eah (RPI) on self-assembly of sub-10-nm gold nanoparticles in nearly perfect hexagonal lattice with excellent long-range order exceeding many microns. H. Yoshida (Hitachi) gave an invited talk on the precise tailoring of microdomain orientation of block copolymers and demonstrated excellent degree of control on self-assembly. R. Jones (NIST) showed how nanoimprinted patterns can be carefully characterized on the sub-10-nm scale using x-ray techniques, whereas P. Hoyle (Vistec Lithography, Cambridge, UK) presented excellent methodology for characterizing high-resolution, e-beam lithography-produced patterns. A. Ferrari (Cambridge) presented the latest work on Raman characterization of ultrathin carbon films, vital both for processing and fabrication of magnetic and cross-point memories.

Various Aspects of Nanoscale Magnets Discussed

(See MRS Proceedings Volume 962E)

Symposium P on Nanoscale Magnets—Synthesis, Self-Assembly, Properties, and Applications brought together a group of researchers interested in the properties and applications of magnetic nanostructures, including thin films, patterned structures, nanoparticles, nanotubes, and nanowires. Applications of these materials ranged from data storage to medicine. The Symposium started with a joint session with Symposium O, showing a range of patterned structures important in patterned media and magnetic memories, for example, ring-shaped structures that may be suitable for magnetic random access memory (W. Jung, MIT; D. Singh, Univ. of Massachusetts; and C. Chen, Univ. of Virginia) and magnetic arrays formed by various self-assembly processes (M. Albrecht, Univ. of Konstanz, Germany; S. Langridge, Rutherford Appleton Lab., UK). Work was presented on high anisotropy nanoparticles such as the L10 materials and anisotropy in nanostructures. At the opposite end of the applications spectrum, K. Krishnan (Univ. of Washington–Seattle) presented work on biomedical applications of magnetic nanoparticles, including both diagnostics and treatment of disease. There was a significant amount of work presented on the structure and properties of nanoparticles, including collective behavior due to interactions, and smaller sessions on molecular magnets (M. Affronte, CNR-INFM; UniMoRe, Modena, Italy) and magnetic oxides such as perovskites (Y. Takamura, UC–Berkeley).

Progress Made Toward Application of Nanowires and Carbon Nanotubes

(See MRS Proceedings Volume 963E)

Significant progress seems to have been made in understanding the detailed mechanisms of CNT growth—a critical issue in ensuring reproducible device characteristics. In this context, A.R. Harutyunyan (Honda Research Inst., Columbus, Ohio) and other speakers in Symposium Q on Nanowires and Carbon Nanotubes talked about the role of the catalyst particle composition, morphology, and the preparation methods of the catalyst.

The use of nanowires such as WS_2 and MoS_2 as tribological materials in orthodontic and medical devices was addressed by R. Tenne (Weizmann Inst., Israel). MoS_2 nanowires were shown to exhibit a semiconducting–metallic–semiconducting transition as a function of pressure.

A large number of talks were presented on the synthesis of branched CNT and nanowire morphologies. The application of branched multi-walled CNTs and nanowires for novel nanoelectronics including switches, logic devices, and high frequency generation was addressed by H. Xu (Lund Univ., Sweden). Recent theoretical and experimental investigations have

MRS Medalist Wonbong Choi Covers Innovations in CNTs

MRS Medalist Wonbong Choi of Florida International University noted that nanotechnology is somewhere between the embryo and early growth stages of its development, with a long way to go to reach maturity. CNTs have a high aspect ratio, high electrical and thermal conductivities, and high rigidity, which make them an ideal material for field emitter applications. The low power consumption of such devices and the ability of electrons to tunnel from cathode to anode at low operating voltage make the technology particularly attractive. However, developing field uniformity has been a challenge. CNT geometry and alignment are factors, as are uniform resistance and circuit design, Choi said.

With a diameter between 10 nm and 25 nm and a length of up to 250 nm, the tip-on-oxide nanowires produced a record 170 µA emission current per single multistage emitter, Choi said. He also noted that CNTs are being developed as components in nonvolatile memory devices, as biosensors that are ultrasensitive to a single molecule of target analyte, and as catalysts coated with ruthenium oxide. Novel Y-shaped CNTs show a mixture of metallic and semiconducting properties; Choi has demonstrated the ambipolar transisting at room temperature (helped to characterize the current–voltage properties of these structures). Markets for CNTs by the year 2010 include nanocomposites (nanogears), nanoprobes, nanosensors, field emitters, and nanotransistors, he said.

Government Seminars Describe Funding Opportunities for Materials Researchers

Early-career materials researchers, curiosity-driven researchers, researchers interested in user-specific basic research, researchers pursuing nano-studies and those pursuing the opposite all found opportunities among the U.S. government agencies represented at the 2006 MRS Fall Meeting.

The Department of Energy offered small discussion groups for early-career investigators to converse in detail on the grant opportunities in their specific area of research. Harriet Kung, director of the Materials Sciences and Engineering Division of the DOE Office of Basic Energy Sciences (BES), described the overall mission and materials funding opportunities in BES. BES has been holding workshops to determine high priority research directions in addressing key scientific challenges in use-inspired energy research, including basic research for the hydrogen economy, solar energy utilization, advanced nuclear energy systems, superconductivity, and solid-state lighting. BES also supports idea-driven research in which researchers focus on long-term research with the goal of gaining fundamental knowledge of materials and their behaviors that may be only peripheral or unconnected to current energy needs. DOE's research interests also include the development of new science-based tools and techniques. Funding is available for both the "use-inspired" and "idea-driven" research to provide the foundations in gaining fundamental new understanding and enabling the discovery and design of new materials to overcome short-term technology showstoppers and to address long-term grand science challenges.

Within the National Science Foundation, W. Lance Haworth, NSF's Acting Director of the Division of Materials Research (DMR), announced some new activities the division has adopted: the Biomaterials Program funds individual investigators and small groups engaged in experimental research covering the study of biologically related materials and phenomena including biological pathways to new materials; the Partnership for Research and Education in Materials (PREM) funds collaborations between minority-serving institutions and DMR-supported groups or centers; and the Materials World Network encourages international collaboration in materials research, education, and technology. Haworth sees the advancement of the frontier of materials research to include new physics and phenomena; new chemistry that will produce transformational materials; the convergence of novel chemical and physical approaches to produce materials of unprecedented complexity and functionality; and the increasing importance of nanoscale research. Haworth emphasized that these areas of materials research are critical for future U.S. competitiveness.

NSF has also established a new Office of Cyberinfrastructure, described by Charles Bouldin, the Program Director of Instrumentation for Materials Research at NSF. The purpose of this office is to develop a cyberinfrastructure that will provide accessible, reusable, and maintainable software for research to replace the current situation where research teams develop their own software, often reinventing the wheel. The existence of a cyberinfrastructure will also provide tools for remote utilization of instruments; it will enhance materials informatics by establishing data interchange standards; and it will produce improved algorithms that bridge the disparate length and time scales often seen in materials research. The sustainability of data in databases will be improved, along with the ability to share data with other researchers in a common format. DMR's efforts to incorporate cyberinfrastructure into its programs are discussed in a draft workshop report, which is available for viewing and comments at Web site www.mcc.uiuc.edu/nsf/ciw_2006 (accessed in February 2007).

At the Department of Energy (DOE) session for early-career investigators, Bonnie Gersten, the program manager of synthesis and processing science, led one of the break-out sessions in which attendees discussed in detail the grant opportunities in their specific area of research.

David M. Stepp of the Army Research Office (ARO) announced that the ARO is looking for unprecedented material properties, not just incremental improvements in existing systems. Stepp emphasized that he is interested in basic, not applied research; his goal is to provide for the soldier of 2031 by realizing unprecedented materials properties today that will enable revolutionary technology and systems for the future soldier. One noteworthy funding program in the agency's arsenal is the Short Term Innovative Research (STIR) program, which provides funds of up to $50,000 over nine months to give a researcher a chance to explore whether or not an intriguing idea has real merit.

Joan Fuller of the Air Force Office of Scientific Research (AFOSR) said that the Air Force basic research program in ceramics provides fundamental knowledge for improving the *performance*, *cost*, and *reliability* of structural ceramics. Structural materials research studies a broad range of materials properties such as strength, toughness, fatigue-resistance, and corrosion-resistance of airframe, turbine engine, and spacecraft materials. The development of new classes of materials for sustained use in the extreme environments experienced by a maneuverable hypersonic vehicle is a renewed emphasis area. Many have viewed the search for structural materials that can withstand the hypersonic operating environment as the quest for "unobtainium." A hypersonic flight vehicle poses many daunting physical and mechanical requirements, said Fuller, that are further complicated if the system is to be affordable, reusable, and sustainable. Key challenges facing the structure or skin of the vehicle include an operating environment that has temperatures in excess of 1500°C in combination with corrosive gases (both oxidizing and reducing) and dynamic pressures in the range of 1,500 psf. However, the engine of the hypersonic vehicle will experience the most demanding environment of the structure with temperatures at the combustor exit in excess of 2500°C. Active cooling can be used to lower temperatures significantly; however, this will create new engineering challenges

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shown that for a symmetric three-terminal device, when finite voltages Vl and Vr are applied in push–pull fashion, with $Vl = V$ and $Vr = -V$, to the left and right branches, the voltage output Vc from the central branch will always be negative. This property is in strong contrast to a symmetric three-terminal device made from conventional diffusive conductors, for which Ohm's law predicts a constant zero output of Vc for all $Vl = -Vr$. This novel characteristic appears even when the device symmetry is broken, provided that $|V|$ is greater than the threshold.

The synthesis and assembly of nanowires through optical scanning methods was addressed by P. Pauzauskie (UC–Berkeley). He showed that light intensity could be used to efficiently "pick and place" nanowires and assemble large-scale systems for diagnostic purposes.

NEMS based on single-walled CNTs were demonstrated in exquisite TEM experiments through the work of J.C. Meyer (UC–Berkeley). He showed that the torsional motion could uniquely distinguish between the two varieties of the (m,n) and (n,m) type.

Symposium Support: ARO.

Meta-Materials Explored at the Milli-, Micro-, and Nanoscale

(See MRS Proceedings Volume 964E)

Meta-materials, the topic of Symposium R, make up a new class of artificially structured composite materials that display superior and unanticipated properties not observed readily in nature and in the constituent materials. Examples of such properties include negative refractive index and transmission gaps for electromagnetic and acoustic waves, colossal reductions in the plasmon frequencies, and magnetic responses in composites made out of nonmagnetic constituents, over frequencies extending to the optical regime.

S. Schultz (UC–San Diego) highlighted practical approaches to achieving a true 2D NIM at mid-IR range. Researchers from Hewlett-Packard in collaboration with researchers at the University of California–Berkeley addressed the realization of negative refractive index in the mid-infrared regime. Application of newly emerging nanoimprint lithography was used to fabricate meta-structures at sub-10-nm IR range. V. Shalaev (Purdue) and N. Engheta (Univ. of Pennsylvania) addressed the realization of such materials in the optical regime. In particular, Shalaev's implementation involved pairs of metallic nanorods embedded in a dielectric matrix, thereby creating an effective medium with permeability less than 1 and reaching negative values at optical frequencies, paving the way for a realization of optical negative refractive index materials and "invisible cloaks" (which require permeability in the 0–1 regime). Engheta discussed metallic (plasmonic) and dielectric nanoparticles and nanowires to realize nanoscale "optical" capacitors, inductors, and transmission lines.

A particular highlight of the acoustic bandgap materials was C. T. Chan's (HKUST, Hong Kong) talk that focused on negative index acoustic materials that used locally resonant constructs that could have negative density and elastic moduli simultaneously. The creation of such locally resonant constructs enables creation of acoustic meta-materials in the subwavelength regime.

The fabrication of hybrid nanostructures using advanced techniques was the focus of N. Halas's group at Rice University and of F. Papadimitrakopoulos's group at the University of Connecticut. The Halas group is focused on creating nanostructures with a wide diversity of shapes, including core–shell structures, nano-flowers, and nano-onions, for example, and exploring and tuning their plasmonic properties, whereas the Papadimitrakopoulos group uses DNA/RNA strands to control the growth, composition, and morphology of nanostructures, as well as precise placement of defects in periodic arrangement of nanostructures.

Symposium Support: Freescale Semiconductor and Motorola, Embedded Systems Research.

Advances Reported in Organic Electronics

(See MRS Proceedings Volume 965E)

OLEDs have been used for flat-panel display applications and, more recently, they have been investigated for low-cost, solid-state lighting applications. With recent development in phosphorescent OLEDs, devices with very high power efficiency have been demonstrated. OLEDs for solid-state lighting require devices with high luminous efficiency, high color rendering index and long life time. To address these issues, S. Forrest (Univ. of Michigan) reported in Symposium S on Organic Electronics—Materials, Devices, and Applications a novel device structure made by sandwiching the green and red phosphorescent emitters between two blue fluorescent emitting layers. With efficient exciton energy transfer, the white-emitting devices exhibit total external quantum efficiency of 19% and power efficiency of 37 lm/W. J. Kido (Yamagata Univ.) also reported very high-efficiency phosphorescent OLEDs. By incorporating high gap host

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since the cooling fuel can degrade the UHTC mechanical properties and decrease overall system performance, said Fuller.

Aran J. Perez of the Office of Naval Research (ONR) said that mitigating corrosion is high on the Navy's research list. The Navy also needs faster, more maneuverable ships with extended operating cycles and reduced maintenance requirements. This means lightweight materials (for better maneuverability) with high strength and durability. Materials that contribute to improving a ship's structural survivability, such as a rapid cure, single coating system for enhanced corrosion control, are what the ONR is looking for, according to Perez. Advanced steels, Ti, Al alloys, cellular materials, advanced composites, and new high-strain actuators and sensors are just some of the research areas of interest.

Representatives from the National Institutes of Health (NIH) identified areas of biology and medicine requiring materials researchers, including medical devices, artificial organs, and drug delivery systems. In addition, researchers in the area of interfacial properties and bulk properties can apply their expertise to solve medical problems. To assist materials researchers in understanding the proposal process in NIH, the agency held a workshop on "How to Write a Successful Research Proposal." Speakers reviewed the requirements for proposals and highlighted distinctions of their respective agencies, with a focus on biomaterials research. Chair of the workshop, Eleni Kousvelari, director of the Center for Biotechnology & Innovation, National Institute of Dental & Craniofacial Research at NIH, introduced the workshop, followed by presenters from NIH and NSF. Materials researcher Phillip B. Messersmith (Northwestern University)—who has obtained funding from NIH—provided practical, step-by-step information on how to submit a proposal and Kathryn Koeller of the Center for Scientific Research at NIH covered the route of a proposal once it reaches the agency. Harsh Deep Chopra, a program director at NSF, presented the "stages of a proposal's life."

and carrier transport materials, power efficiency of 130 lm/W has been demonstrated for green-emitting devices.

Organic thin-film transistors have received a lot of attention for flexible display applications. With very thin (2–5 nm) self-assembled organic multilayers as gate dielectrics, T. Marks (Northwestern) reported organic thin-film transistors with operating voltage less than 1 V. The devices exhibit excellent insulating properties with leakage current densities as low as 1 nA/cm^2. These self-assembled multilayers enable organic thin-film transistors to function at very low source-drain and threshold voltages (<1 V). I. McCulloch (Merck Chemicals) reported thin-film transistors fabricated from a new semiconducting thiophene polymer with mobilities up to 0.6 cm^2/V-s. These devices show promising stability when they are kept at low humidity.

Materials and Properties of Ferroelectrics and Multiferroics Explored
(See MRS Proceedings Volume 966E)

The major purpose of Symposium T was to encourage exchange and discussion between the still largely disjunct communities of ferroelectrics and multiferroics research. In that sense, contributions stressing the intricate connection between the ferroelectric state and the magnetic properties of matter may be called one highlight of the symposium.

In particular, spin-spiral ferroelectrics were discussed as a novel type of multiferroic in which magnetic spiral structures reduce the symmetry of a crystal in a way such that a spontaneous polarization and, thus, ferroelectricity, become an allowed property of the material. Compounds of this type were discussed by S.-W. Cheong (Rutgers), and T. Kimura (Bell Labs/Lucent Technologies). It was pointed out that because of the "spintronic nature" of the ferroelectric state it is often straightforwardly possible to manipulate the spontaneous polarization by magnetic fields or the magnetic order by electric fields. Present drawbacks are the smallness of the spontaneous polarization in these ferroelectrics and the generally low ordering temperatures. However, according to Kimura, a large number of potential spin-spiral ferroelectrics are known which may offer a way out of at least the first of these drawbacks.

From the point of view of materials, an exceptionally large number of contributions was devoted to $BiFeO_3$ and (Pb, Zr) TiO_3. A focus topic of research on $BiFeO_3$ was the growth, geometry, and manipulation of its ferroelectric domains. High-resolution images of ferroelectric domains were obtained in the group of R. Ramesh (UC–Berkeley), and both Ramesh and S. Fujino (Univ. of Maryland) discussed the possibility of using the ferroelectrically controllable antiferromagnetism of $BiFeO_3$ for controlling exchange bias in $BiFeO_3$-based heterostructures.

Advances Reported in *In Situ* Characterization of Film Growth and Interface Processes
(See MRS Proceedings Volume 967E)

Symposium U covered ongoing research on studies of film growth and interface processes with a focus on recent advances in *in situ* characterization techniques, including ion scattering and mass spectrometry, electron microscopy, RHEED, SPM, optical monitoring (e.g., spectroscopic ellipsometry and emission spectroscopy), and *in situ* x-ray analysis. From the presentations, it became clear that not only diffraction and spectroscopy techniques, but also "real-space" analysis techniques are now capable of real-time characterization of growth processes. As an example, Y. Homma (Tokyo Univ. of Science) showed recent advances in *in situ* observation using SEM to elucidate the growth process during CVD of single- and multi-walled CNTs. Another example is the recent development in real-time AFM during PLD of complex oxides,

Graduate Students Receive Gold and Silver Awards

During the Awards Ceremony held on November 29 at the 2006 Materials Research Society Fall Meeting, graduate student finalists received Gold and Silver Awards.

Gold Graduate Student Awards went to (left to right): **Jie Xiang** (Harvard University); **Xing Chen** (University of California–Berkeley); **Paul H. Erhart** (Technische Universitat Darmstadt); **Peter J. Pauzauskie** (University of California–Berkeley); **Fabien Sorin** (Massachusetts Institute of Technology); **Daeyeon Lee** (Massachusetts Institute of Technology); and **Ming Tang** (Massachusetts Institute of Technology).

Silver Graduate Student Awards went to (front row, left to right): **Shivaraman Ramachandran** (North Carolina State University), **Soong Ho Um** (Cornell University), **Yangang A. Xi** (Rensselaer Polytechnic Institute), **Samrat Choudhury** (The Pennsylvania State University), **Beth S. Guiton** (University of Pennsylvania), **Friederike Fleischhaker** (University of Toronto), **Jennifer I.-L. Chen** (University of Toronto), **Arief S. Budiman** (Stanford University), **Boaz Pokroy** (Technion–Israel Institute of Technology), and **Kuangshin Tai** (Massachusetts Institute of Technology); and (back row, left to right): **Hui Wang** (Rice University), **Aihua Fu** (University of California–Berkeley), **David C. Coffey** (University of Washington), **Aaron D. Franklin** (Purdue University), **Ludovico Cademartiri** (University of Toronto), **Scott C. Warren** (Cornell University), **Mikel E. Barry** (University of California–Berkeley), **Kris C. Wood** (Massachusetts Institute of Technology), **Zixiao Pan** (Northwestern University), **Jennifer J. Riesz** (University of Queensland), **Jing Zhou** (University of California–Berkeley), **Yi Li** (Georgia Institute of Technology), and **Jinsong Huang** (University of California–Los Angeles).

shown by Broekmaat (Univ. of Twente, the Netherlands).

Symposium Support: k-Space Assoc., Inc,; LANL, Superconductivity Technology Center; Staib Instruments, Inc.; and Twente Solid State Technology B.V.

Advances in Communications Devices Relies on Heterogeneous Integration of Materials for Passive Components

(See MRS Proceedings Volume 969)

The next generation of polyfunctional and multi-technology devices calls for novel heterogeneous and passive integration and packaging options to enable multidisciplinary applications in the optical, communication, military, automotive, medical, sensing, and memory domains. Symposium W covered the current trends, requirements, and recent developments in electronic materials and processing toward integration of smart systems and MEMS for future application in wireless (rf, microwave, millimeter, and THz frequency range) communication and portable devices.

The Symposium started with a review and update of the status of low-temperature co-fired ceramic components by D. Suvorov (Inst. Jozef Stefan, Slovenia). The role of interfaces and chemical compatibility, and how they influence module design, was discussed.

The road from design to actual embedded circuit elements and applications on different substrates was demonstrated and discussed by J.-P. Maria (NCSU) and A. Kingon (NCSU), as well as by other speakers. Current miniaturization and integration strategies and processes for medical and RF systems in package were also discussed. Here, F. Murray (NXP Research, France) reported the highest capacitance density known to be integrated in silicon in an industrial environment. Furthermore, the reported values of 250 nF/mm^2 are almost 10 times more than the currently available values obtained with standard semiconductor processes and materials. Successful above-IC integration of AlN thin film BAW filters was reported by M.-A. Dubois (CSEM, Switzerland).

An engineering perspective on temperature-insensitive, electric-field tunable devices was presented by S.C. Tidrow (ARL). The Symposium was complemented by a series of presentations on MEMS and NEMS devices and magnetic components.

Symposium Support: NXP Research.

Development of Proton Conductors Emphasized

(See MRS Proceedings Volume 972)

Symposium AA on Solid-State Ionics focuses on research related to ionically conducting (e.g., protons, oxygen ions) materials and devices. The Symposium emphasized development of proton conductors and had sessions on fundamental materials R&D, characterization, and materials for batteries, sensors, membranes, and fuel cells.

Environmental stewardship is placing increasing demands on emission control of vehicle exhausts. For spark-ignited, direct-injection engine exhausts, these demands are largely met with the use of a three-way catalyst capable of simultaneous remediation of CO, NO*x*, and hydrocarbons. However, current generation three-way catalysts lose their effectiveness for NO*x* reduction in the presence of excess oxygen. Two technologies proposed for NO*x* remediation of these exhausts are the lean-NO*x* trap (LNT), and selective catalytic reduction (SCR). Both of these approaches will require on-board NO*x* sensors to control trap regeneration or reagent injection. L.P. Martin (LLNL) presented results from his work on a new method for NOx sensing using impedance spectroscopy. By analyzing the phase angle shift, Martin's group has been able to accurately measure the NOx concentration at a given temperature. Furthermore, their work demonstrates that this technique may effectively eliminate baseline drift, which limits most other approaches.

Membranes will play a key role in the future for purifying hydrogen and oxygen and the production of syngas and have the potential to greatly reduce system cost. Researchers at AirProducts have developed and scaled-up an oxide-based membrane stable at 800°C in a large chemical potential gradient capable of producing syngas. The membrane operates by ionizing oxygen in air, which diffuses through the membrane and reacts with natural gas to produce hydrogen and carbon monoxide. Key to this work is the development of a seal that is stable in both the reducing and oxidizing environments of the membrane.

Methods Explored to Enable Mobile Energy

(See MRS Proceedings Volume 973E)

The purpose of Symposium BB was to develop methods to integrate an energy storage device with an application(s) mounted to a mobile system platform. In this context, the presentations closely related to this idea were concerned with increasing the storage capacity of a nearly planar battery configuration through the development of a 3D battery configuration where height of the battery is comparable to the planar dimensions. For example, the first presentation was concerned with a general method of forming 3D ordered macroporous or inverse opal materials that can result in improved rate performance of electrodes in lithium-ion batteries. Other talks dealt with microfabricated, solid-state, thin-film batteries for rf-MEMS powering and 3D battery integration that would be compatible with a high degree of IC integration.

In the realm of larger energy storage devices compared with smaller devices used for MEMS applications or IC circuits, there was a presentation concerned with combining structural materials with power and energy for army applications through the use of multifunctional structural composite materials. The aim of the program is to develop mechanically robust solid polymer electrolytes that will add functionality to pre-existing composite structures to reduce the need for dedicated, nonstructural batteries. In order to achieve practical results with this approach, one may not need the most optimum performance characteristics from each component in order to be successful.

A number of presentations addressed the energy storage device itself such as batteries, fuel cells, and capacitors and energy conversion using semi-transparent amorphous silicon solar cells on inexpensive plastic substrates with solar cell efficiencies on the order of 10–11%. The theme in these presentations was the need to increase battery-specific energy density through high-voltage couples such as lithium-oxygen, development of super-capacitors, and extension of fuel-cell life performance through reduction of platinum loss in PEM fuel cell cathodes. Once these issues are resolved then the potential for integration for these energy storage devices into mobile platforms may be more feasible.

Mechanics of Biological and Bio-Inspired Materials Investigated at Micro- and Nano-Length Scale

(See MRS Proceedings Volume 975E)

Biological materials exhibit structural hierarchy often not seen in engineered materials. As a result of this complex structure and hierarchy the mechanical behavior of these materials is often difficult to both characterize and model. This is also true for many bio-inspired systems. Symposium DD had presentations on mechanics of biological materials such as bone, teeth, spider silks, wasps, malaria cells, seashells, wood, cartilage, lobsters, and seeds. Modeling methods ranging from molecular mechanics to finite element were described to simulate mechanics of a variety of biological materials.

Addressing the hierarchy of structure in human teeth, S. Weiner (Weizmann Inst. of Science, Israel) mapped nanoscale displacements during loading of human teeth. W. Soboyejo (Princeton) did experiments that involved the flow of water in order to measure the mechanics of cells. To understand the mechanics of nacre, the inner layer of seashells, D. Katti (North Dakota State Univ.) used multiscale characterization and modeling methodologies that spanned finite element at the microscale to molecular dynamics at the subnanometer scale. R. Lewis (Univ. of Wyoming) showed results from his group indicating the use of novel protein design strategies to create spider silk fibers with tailored mechanical properties.

Smaller is Stronger

(See MRS Proceedings Volume 976E)

"Smaller is stronger" was the overwhelming theme of Symposium EE, Size Effects in the Deformation of Materials—Experiments and Modeling, which brought experimentalists and modelers together to discuss how and why microstructural or geometric lengthscale affects mechanical behavior.

The highlight of the symposium was an overview by D. Dimiduk (WPAFB) of a method of microcompression testing developed with M. Uchic (WPAFB) a few years ago. The method utilizes a nanoindenter to uniaxially compress microscale columnar structures typically fabricated using focused-ion beam milling. In addition to the usual "smaller is stronger" observation for metal plasticity, Dimiduk showed that for column diameters down to a few microns the spacing of dislocation braids remained nominally constant. Two presentations followed on x-ray microdiffraction of microcompression experiments, with key results that were significantly different, although not necessarily contradictory. R. Maass (Paul Scherrer Inst., Switzerland) showed how plastic strain evolves in the form of crystal rotations, as observed with *in situ* Laue microdiffraction during compression of >2-μm diameter Au columns. Subsequently, A. Budiman (Stanford) presented his Laue microdiffraction observations that no measurable crystal rotations resulted after microcompression of submicron Au columns; Laue reflections measured before and after deformation showed no streaking. This may be indicative of a critical size in which the dislocation storage response changes, and could be supported by Dimiduk's TEM observations. D.M. Weygand (Univ. of Karlsruhe, Germany) captured the increase in strength with decreasing diameter using dislocation density modeling. Assuming a constant initial dislocation density for all column sizes, Weygand also observed that the extent of scatter in stress versus strain response increased with decreasing diameter, signifying a greater dependence on the specific pre-existing dislocation arrangement in smaller volumes.

Symposium Support: Advanced Micro Devices, Inc.; Applied Materials, Inc.; FEI Co.; Hysitron, Inc.; Novellus Systems, Inc.; and Spansion LLC.

Relations Between Processing, Structure, and Mechanical Properties of Composites Materials Highlighted

(See MRS Proceedings Volume 977E)

Presentations in Symposium FF highlighted the processing–structure– mechanical property relations in a broad range of metal, ceramic, and polymer-based nano- and microstructured composite materials. Both experimental and theory/modeling/simulation techniques in the study of mechanics of composites were discussed. The Symposium included a tutorial session that focused on recent developments in experimental techniques such as *in situ* mechanical testing under x-ray and neutron beams (S. Van Petegem, Paul Scherrer Inst., Switzerland) and 3D atom probe (X. Sauvage, CNRS, Rouvray, France),

Poster Prizes Awarded at the 2006 MRS Fall Meeting

The 2006 Fall Meeting Chairs awarded prizes for the following best poster presentations: (D15.17) **Far-Field Arrangement of Proteins in a Zero-Mode Waveguide for Single Molecule Imaging**, T. Tanii, H. Sonobe, R. Akahori, T. Miyake, N. Shimamoto, and I. Ohdomari (Waseda Univ., Tokyo); and T. Ueno and T. Funatsu (The Univ. of Tokyo); (K10.1) **Ferromagnetic Ordering at Room Temperature in Co:ZnO Nanoparticles**, S. Chaudhary, K. Bhatti, S. Kundu, S.C. Kashyap, and D.K. Pandya (IIT, New Delhi); (L7.13) **Structural, Electronic, and Optical Analysis of Luminescent Si-Nanocrystal Systems**, T. Roschuk, O.H.Y. Zalloum, J. Wojcik, and P. Mascher (McMaster Univ., Canada); and D. Comedi (McMaster Univ., Canada; CONICET and Universidad Nacional de Tucumán, San Miguel, Argentina); (O7.3) **Size and Composition Dependent Magnetic Properties of Co/Pt Nanodot Arrays**, S.C. Park, J. Bang, and J.S. Ha (Korea Univ., Seoul); and C.H. Bae and S.M. Park (Kyunghee Univ., Seoul); (Q10.4) **General Synthesis and Properties of Novel Transition Metal Silicide Nanowires**, A.L. Schmitt, L. Zhu, and S. Jin (Univ. of Wisconsin–Madison); (Q15.50) **Intrinsic Characteristics of Semiconducting Oxide Nanobelt Field-Effect Transistors and Their Applications**, Y. Cheng and P. Xiong (Florida State Univ.); L. Fields and J.P. Zheng (Florida A&M University; Florida State Univ.); and R. Yang and Z. Lin Wang (Georgia Tech); (W3.1) **Ferrite Plating By Spin Spray Technique Without Using Any Strong Oxidizing Agents**, S.A. Krishnan, M. Nobuhiro, W. Tomoaki, and Y. Masahiro (Tokyo Inst. of Technology, Yokohama); and T. Masaru and A. Masanori (Tokyo Inst. of Technology, Tokyo); (DD3.13) **Fracture Behavior and Shear Resistance of Lobster Cuticle**, C. Sachs, H. Fabritius, and D. Raabe (MPI–Duesseldorf, Germany); (MM7.11) **Portable, Low-Cost, *Ex-Situ* NMR with Laser-Lathe Microcoils**, V. Demas, J. Franck, J. Reimer, and A. Pines (UC–Berkeley; LBNL); and J. Herberg, V. Malba, T. Bernhardt, and R. Maxwell (LBNL); (QQ6.22) **Electrochemical Morphogenesis of Micron-Size Cu_2O Crystals**, M.J. Siegfried and K.-S. Choi (Purdue Univ.).

with specific applications to composite materials. Several invited speakers highlighted the fundamental issues in the processing and mechanical behavior of composites produced by severe plastic deformation (Sauvage; R. Pippan, Austrian Academy of Sciences; D. Raabe, MPI–Düsseldorf; K. Han, Natl. High Magnetic Field Lab., Florida; G. Wilde, Forschungszentrum Karlsruhe, Germany). The application of these metal–metal composites as electrical conductors in high magnetic fields was also discussed. Fundamental aspects of the deformation of metal–matrix composites were discussed, including load transfer from metal to ceramic reinforcement (D.C. Dunand, Northwestern), size effects in pressure infiltrated metal–matrix composites (A. Mortensen, EPFL), and effects of microstructure on the wear behavior (R.I. Todd, Univ. of Oxford, UK). The unusual mechanical behavior of ceramic composites such as extremely low creep rates in silicon nitride/silicon carbide nanocomposites and high fracture toughness in alumina reinforced with carbon nanotubes and niobium were highlighted (A.K. Mukherjee, UC–Davis). Several invited presentations showed new insights in the mechanical behavior of composites involving amorphous phases. For example, high ductility in metal films on polymer substrates used in flexible electronics (Z. Suo, Harvard), light-weight Mg composites involving amorphous phases (E. Ma, JHU), and suppression of shear bands in nanometer scale metallic glasses in crystalline/amorphous nanolayered composites (F. Spaepen, Harvard). Another class of composites highlighted was nanoscale metallic multilayers, including invited presentations on size effects in the plasticity (M. Verdier, LTPCM-CNRS, St. Martin d'Heres, France), enhanced internal friction (R. Cammarata, JHU), and combination of high strength and high-radiation damage tolerance (R. Hoagland, LANL). Mechanical properties of polymer-based composites (R.A. Pearson, Lehigh Univ.), and structural hierarchy and mechanics of bio-inspired composites (J. Aizenberg, Lucent Technologies/Bell Labs.; H. Gao, Brown Univ.) were also highlighted.

Symposium Support: Ambassade de France in the United States and LLNL.

Insights Provided into Research Directions for Multiscale Modeling of Materials

(See MRS Proceedings Volume 978E)

Symposium GG on the Multiscale Modeling of Materials provided an overview of the methods and algorithms available to simulate materials structure, properties, and performance. The invited speakers outlined methodologies to extend the simulation over several orders of magnitude both in space and time. The Symposium also showcased new developments in coarse-grain modeling, in particular for applications in soft matter. In general, sequential or hierarchical methods seem to be the preferred choice for multiscale modeling. In these methods, information from accurate *ab initio* or molecular dynamics calculations is transferred to longer scale simulations such as Monte Carlo or phase-field methods. Several speakers highlighted successful applications of this methodology in the areas of crystal growth, defect evolution in irradiated materials, and semiconductor processing. In addition, several talks introduced developments in the quasicontinuum method and its extension to complex crystals, novel methods to speed up *ab initio* molecular dynamics calculations, and new algorithms for structure optimization. Joint sessions held with Symposia EE, FF, and JJ featured interdisciplinary research and were very successful. Researchers from GM illustrated the impact of multiscale modeling on industry by using molecular dynamics simulations to understand grain-boundary sliding and to improve their FEM models for superplastic forming.

Symposium Support: LLNL.

Focus Given to Phase Transformations in Inorganic Materials

(See MRS Proceedings Volume 979E)

Symposium HH, dedicated to Georges Martin (CEA, France), covered a wide range of active research topics in the area of thermodynamics and kinetics of phase transformations in inorganic materials. Recent advances in the first-principle calculation of thermodynamic properties of phases and defects were highlighted, including carbides in steels (M. Sluiter, Delft Univ. of Technology, the Netherlands), and vacancies, self-interstitials, and their complexes with solute and impurities in iron and zirconium (F. Willaime, CEA Saclay, France). M. Asta, (UC–Davis) and Y. Ashkenazy (Hebrew Univ., Israel) studied the properties of solid–liquid interfaces at equilibrium and under deep undercool-

Inaugural Materials Film Festival Applauds Amateur and Professional Efforts

The Materials Research Society's inaugural materials film festival announced winners of the top three films in two categories: amateur and professional. Voting was done during the week of the meeting by meeting attendees. The announcements and viewing of the winning films were held during Symposium X.

Professional Category

1st place
"Get Perpendicular," by Zvonimir Bandic, Hitachi Research (Bandic officially submitted the film and accepted the award on behalf of Hitachi. He is not the author of the film.)

2nd place
"When Things Get Small," by Ivan Kohn Schuller, University of California, San Diego

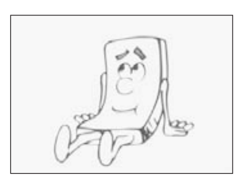
3rd place
"Stretchable Silicon," by Alex Jerez, Beckman Institute, University of Illinois

Amateur Category

1st place
"Gecko—On Shape and Function of Gecko Foot-Hair," by Jose Berengueres, Tokyo Institute of Technology

2nd place
"Muscular Thin Films: Biohybrid Materials for Soft Robotics," by Adam Walter Feinberg, Harvard University

3rd place
"Material Combat," by Jonathan Lee Hollander, University of Cambridge



From "Get Perpendicular" Hitachi

ings, respectively. The role of chemical flux coupling in the atomistic kinetic evolution of model superalloys was highlighted by Martin, whereas a new self-consistent analytic derivation of these flux coupling and related correlation effects in concentrated alloys was presented by M. Nastar (CEA, France). A. Finel (CNRS-ONERA, Chatillon, France) proposed a rigorous derivation of the continuum kinetic description known as phase-field modeling by coarse-graining a microscopic description, thus making this phase-field model quantitative. Several speakers presented exciting developments on grain boundaries and triple junctions in polycrystalline and nanocrystalline materials; D.J. Srolovitz (Yeshiva Univ., New York), in particular, used an innovative mathematical approach to generalize in three dimensions the well known von Neumann equations for grain growth. The importance and benefits of characterizing microstructures in three dimensions by atom probe tomography or by tomographic reconstruction of transmission electron micrographs were emphasized by several speakers, including D. Blavette (Univ. of Rouen, France), D.N. Seidman (Northwestern), and S. Matsumura (Kyushu Univ.). A full session was dedicated to radiation effects, illustrating recent developments in the ability to characterize irradiation-induced defects—for instance, by C.P. Flynn (UIUC) in the case of surfaces—and to investigate the nonequilibrium microstructures stabilized by irradiation, as discussed by R. Averback (UIUC). L. Kubin (CNRS-ONERA, Chatillon, France) emphasized the role played by length scales in the work-hardening of plastically deformed crystals. The session on amorphous materials, with contributions from K.H. Samwer (Univ. of Gottingen, Germany), S.G. Mayr (Univ. of Gottingen, Germany), M. Atzmon (Univ. of Michigan), and J.H. Perepezko (Univ. of Wisconsin–Madison), revealed the important recent progress made in identifying the mechanisms responsible for plasticity in metallic glasses. M. Descamps (Univ. of Lille, France) showed that some of the concepts introduced and developed by Martin for solids subjected to external forcing were also applicable to the processing of molecular materials, in particular, pharmaceutical compounds.

Symposium Support: NSF–DMR.

Interest in Advanced Intermetallic-Based Alloys Driven by New Demands

(See MRS Proceedings Volume 980)

In Symposium II, highlights in structural intermetallics included β-phase-containing TiAl alloys and novel alloys possessing laminated nanostructures, new iron aluminides for higher temperatures than considered previously, nickel aluminides competing with advanced superalloys, and growing sophistication in theoretical/computational modeling. In each case, research is built on the understanding of the past decades but is now re-energized by the beginnings of industrial applications (TiAl) and new demands (Fe-Al, Ni-Al, and silicides) for higher temperature materials with superior corrosion resistance (B.P. Bewlay, GE R&D).

The potential of "traditional" structural intermetallics for functional applications was demonstrated by T. Hirano (NIMS, Japan) who showed that Ni_3Al in the form of thin foils, 30-μm thick, exhibit high catalytic activity for methane decomposition, resulting in high hydrogen production. The catalytic activity was enhanced above 713 K and increased with increasing reaction time, accompanied by a methane conversion rate higher than 98%.

Intermetallics have received increasing attention as advanced thermoelectric materials. H. Inui's group at Kyoto University, Japan, demonstrated that the thermoelectric properties of semiconducting Re- and Ru-silicides can be improved significantly by atomic-scale defect engineering. The control of the concentration and arrangement of vacancies was accomplished by ternary additions as well as by the introduction of shear structures (e.g., adaptive structure).

In the area of ferromagnetic L10 structure-based alloys, K. Barmak (CMU) described the role of elemental composition in attempts to control the kinetics of the ordering transformation in $Fe_xPt_{1-x}M$ (M = Cu or Ni) nanocrystalline thin films. This work is of basic interest and of significant technological relevance to the manufacture of thin-film magnetic recording media with increased data storage capacity based on these materials.

Symposium Support: Boehler Schmiedetechnik GmbH; Daido Steel Co.; Ishikawajima-Harima Heavy Industries Co.; JEOL, Japan; JEOL USA, Inc.; Materials Design Technology Co.; ORNL; and Tokyo Inst. of Technology.

Structural and Refractory Materials Studied for Fusion and Fission Technologies

(See MRS Proceedings Volume 981E)

Radiation-induced damage in structural and refractory materials remains an essential problem limiting materials application. Though intensively studied, the mechanisms of the defect evolution are not fully understood. L. Van Brutzel (CEA-Marcoule, France) performed atomic-scale modeling to study defect production, their spatial distribution, and their clustering in UO_2 matrix under self-irradiation due to α-decay, as discussed in Symposium JJ. Energetic displacement cascades were simulated up to 80 keV energy of the recoil nucleus. Long-term behavior was studied by investigating cascade overlaps, which were initiated by different primary knock-on atoms within the same box. Cascade–grain boundary interaction leading to the dissipation of cascade energy was also studied. It was observed that as the radiation dose increased, so did the number of point defects created. Irradiation-produced vacancies were more susceptible to clustering than were interstitials.

A. Kimura (Kyoto Univ., Japan) discussed novel nanosized ODS steel developed for application in super critical pressurized water reactors. Yttria particles smaller than 10 nm in diameter were dispersed by means of mechanical alloying. Furthermore, increased chromium

Funding for Basic Materials Research Requires Advocacy from Research Universities

William B. Bonvillian, director of MIT's Washington DC office and former legislative director and chief counsel to U.S. Senator Joseph Lieberman, working on science and technology policies and innovation issues, gave a picture of the role research universities need to play in innovation. Universities have advanced from strictly basic research to a model of discovery and innovation as is evident in start-ups and entrepreneurs stemming from the research laboratories. Currently, the U.S. government funds one-third of R&D and industry funds two-thirds. However, industry invests its portion in development, whereas the government supports basic research. The U.S. economy is driven by innovation, such as the information technology revolution in the 1990s and biotechnology currently, rather than by natural resources. However, this does not automatically lead to funding of the physical sciences by the federal government. Bonvillian said that research universities need to serve as advocates for funding of basic research and to educate scientists on policy as well as discovery and innovation.

(14–22 wt%) and aluminum (4.5 wt%) contents were chosen in order to increase the corrosion resistance of the steels. ODS steels showed high-temperature strength, high resistance to corrosion, and an extremely high resistance to neutron irradiation (~400–525°C at 1–15 dpa) characterized by "irradiation hardening accompanied by no-loss-of-elongation."

Symposium Support: LLNL.

FIB Becomes Instrumental 3D Materials Analysis Tool

(See MRS Proceedings Volume 983E)

FIBs are instrumental in research ranging from subwavelength optical imaging to nanomanipulation to nanomechanics to biological applications including the determination of what causes the color of a butterfly wing. The FIB has become an extremely versatile tool that enables similar processing for either hard (ceramics and metals) or soft (polymers and biological) materials. Even cross sections of composites of both hard and soft materials are readily achieved with the FIB. Presentations in Symposium LL showed that FIBs remain most useful for drilling small holes or apertures, especially for advanced optical imaging or for molecular separation filters. Several groups have taken advantage of surface plasmon photonics to obtain visible light through a nanohole, to the extent that some even get more intensity out than they shine in. FIB aids the development of electrochemical imaging by processing special AFM tips and biosensors. A mainstay of FIB tool use is for TEM sample preparation, with numerous advances such as site-specific extraction of semiconductor plug (or via) geometries directly onto tomography holders enabling 360° analyses. A similarly (FIB) shaped pillar is useful for correlating defect structure and nanoindentation testing of mechanical properties. Micromanipulators have become instrumental additions to FIBs for extraction and probe testing; and the FIB in turn aids in the processing of nanomanipulators such as three-fingered tweezers. With add-on techniques such as EBSD and EDS, the FIB has become an instrumental 3D materials analysis tool, providing an important link of microstructural understanding between an optical micrograph and an HRTEM image. Although FIB-assisted CVD can grow a complex 3D shape as sophisticated as a nanowineglass, the FIB remains primarily an etching tool. At the nanometer scale, however, more understanding and modeling are needed to determine what causes sputter yields to change, as well as what controls the resulting surface topographies whether they are self-organized or sculpted curved shapes. Furthermore, the FIB continues to simplify the cross-sectional revelations of difficult and fragile materials, such as bringing to light the nanoshapes that provide color to the butterfly.

Symposium Support: AMETEK, Inc.; Carl Zeiss NTS GmbH; E.A. Fischione Instruments, Inc.; FEI Co.; Hitachi High-Technologies Corp; JEOL USA, Inc.; and LLNL.

MRS Medalist Pulickel M. Ajayan Discusses Controlled Assembly of CNT Architectures

"Buckminster Fuller is probably the most quoted person in the arena of carbon without doing much work in it!" said Pulickel M. Ajayan of Rensselaer Polytechnic Institute in his MRS Medalist presentation. With the focus of his talk on the growth and form of nanotubes, Ajayan described recent developments in his laboratory on the fabrication of CNT-based architectures tailored for various applications. He started with basic growth of a nanotube from a catalyst nanoparticle, a process still not well-understood. Ajayan's group uses a fairly simple piece of equipment to grow nanotubes using a thermal CVD process. They can now grow nanotubes up to 1 cm in length. They are also able to grow nanotubes on metallic substrates, such as Ni-Cr alloys. The nanotubes tend to grow better on SiO_2 substrates, and organized architectures can thus be created by appropriately designing the SiO_2 substrate structures. Ajayan also discussed FIB modification of nanotubes to straighten nanotube networks for device structures. Super-compressible (up to 80%) CNT films can be formed and these are completely resilient. Ajayan described using these to create a CNT film membrane filter wherein the pore size can be controlled by compressing the film. This membrane can be used for protein filtration with a size range of 5–15 nm for the protein molecules. He concluded by summarizing the current status of CNTs, including applications such as ESD, SONY batteries, and AFM probes. He expects to see future applications in polymer and metal-matrix composites, field-emission displays in the near term, and electronics, sensors, membranes, and nanobiotechnology in the long term. Manufacturing and nanoscale engineering continue to be challenges, he said.

Magnetic Resonance Aids in Development and Understanding of New Materials

(See MRS Proceedings Volume 984E)

Nuclear magnetic resonance (NMR), magnetic resonance imaging, and electron spin resonance have been used extensively in many areas of materials research including hydrogen storage materials, fuel cells, spintronics, actinide materials, environmental samples, polymeric materials, and nanomaterials. Symposium MM focused on new developments of magnetic resonance technologies for materials science. A tutorial at the beginning of the symposium covered magnetic resonance in polymer science and glass technology, which was presented by R.S. Maxwell (LLNL); magnetic resonance studies on hydrogen storage materials, presented by R.C. Bowman (JPL); and theoretical calculations of magnetic resonance properties for materials science, presented by G. Fitzgerald (Accelrys, Inc.).

One of the highlights of this conference was a talk by B. Blümich (Aachen Univ., Germany), in which he discussed nondestructive testing of materials by single-sided NMR. As an inventor of the NMR MObile Universal Surface Explorer (MOUSE), Blümich discussed some of the uses of this revolutionary system, which included addressing the defect analysis of rubber products, the lifetime prediction of polymer pipes, the stratigraphy of skin and old master paintings, and investigations of the skulls of mummies, including ancient Egyptian mummies and the legendary "Ice Man."

In a joint section with Symposium OO on actinides, I. Farnan (Cambridge) and H. Cho (PNNL) discussed their work on implementing radiological NMR and its use in combination with *ab initio* simulations in identifying and quantifying radiation damage caused by uranium and plutonium in ceramics. They can locate the damaged crystalline and amorphous regions with this technique to reveal the nature of radiation-induced changes in these materials.

Symposium Support: Accelrys, Inc.; Bruker Biospin Corp; LLNL; Spectra Stable Isotopes Tecmag, Inc.; and Varian, Inc.

Progress Made in Study of Materials Research at High Pressure

(See MRS Proceedings Volume 987E)

The development of new methods in static and dynamic experiments and theoretical calculations has revolutionized studies under high pressure. The synthesis of superhard materials under conditions of very high pressures and temperatures is the Holy Grail of materials sciences, as discussed in Symposium PP. Noble metals do not easily form compounds with other elements, but this can be changed under pressure. J. Crowhurst (LLNL) reported that the platinum and iridium nitrides synthesized under conditions of 50 GPa and 2500 K contain pairs of single-bonded nitrogen atoms. Contrary to what has been previously thought, the stoichiometry of the material is MeN_2 (Me = Pt,Ir) and they form pyrite–like structures, determined from x-ray diffraction, Raman spectroscopy, x-ray photoemission spectroscopy, and first-principle theoretical calculations. The materials possess an extremely high bulk modulus (350–400 GPa) and are recoverable to ambient conditions. The presence of nitrogen atom pairs in the structure stabilizes the fcc-like metal structure, making it superhard.

The Symposium also included invited speakers Y. Katayama (Japan Atomic Energy Agency), D. Ceperley (UIUC), I. Goncharenko (CNRS–Gif-sur-Yvette, France), H.-K. Mao (Carnegie Inst. of Washington), and K. Syassen (MPI–Stuttgart). Y. Zhao (LANL) led a tutorial session on superhard materials in which practical approaches for the synthesis of these novel materials was outlined. The tutorial session on CVD diamonds, led by C.-S. Yan (Carnegie Inst. of Washington), explored new methods for determining the composition–property relationships in diamond fabricated with a new high growth-rate process.

Symposium Support: Carnegie/DOE Alliance Ctr.; LLNL, Chemistry and Materials; and LLNL, Science & Energetic Materials Ctr.

Solid-State Chemistry of Inorganic Materials Explored

(See MRS Proceedings Volume 988E)

Symposium QQ addressed recent advances in the solid-state chemistry of porous, nano-, and bulk inorganic materials and their impact on devices and technology. D.A. Keszler (Oregon State Univ.) described printable oxide electronics, with the notable novelty that many of the functional coatings described were amorphous oxides and yet still offered remarkable properties. C. Murray (IBM) described how combinations of highly monodisperse nanoparticles of two different materials could be self-assembled into a veritable zoo of supercrystal lattices, with applications demonstrated in the area of thermoelectrics. M. Antonietti (MPI–Postsdam) described novel and simple routes to functional oxide nanomaterials such as a variety of perovskite titanates. P. Davies (Univ. of Pennsylvania) spoke on controlling tetragonality in novel Bi-based polar materials and, in addition, described some unusual A-site vacancy orderings in polar perovskites. Z. Hiroi (Univ. of Tokyo) described the rattling behavior of cations in pyrochlore superconductors, and A. Maignan (CNRS–Caen, France) described how large families of magnetic oxides are also promising candidates for thermoelectric energy conversion. J. Li (Rutgers) suggested simple ways of reducing the dimensionality of bulk II–VI semiconductors, thereby obtaining crystals that were naturally quantum-confined. T.M. Nenoff (SNL) spoke on confined water in porous materials and how the nature of the water has crucially dictated ion exchange behavior. J. Long (UC–Berkeley) described porous crystalline hybrids for hydrogen storage, obtained through rational design. J.D. Martin (NCSU) suggested from *in situ* studies of crystallization that a number of current ideas on how crystals nucleate and grow might require rethinking. A. Stein (Univ. of Minnesota) described the extensive work on porous inverse opals and how hierarchical structures can be obtained.

Symposium Support: NSF and ACS, Petroleum Research Fund.

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